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A SIMULATION ANALYSIS OF A SUPPRESSION OF ENEMY AIR DEFENSE (SEAD) OPERATION

by

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Traditional SEAD operations rely on Wild Weasel aircraft equipped with Anti-Radiation missiles. This combination of real-time target acquisition capability with high precision weaponry has rendered surface-based radar systems vulnerable and ineffective. As a result, SEAD operations are decoupled from the slow and error-prone intelligence gathering and evaluation process proceeding conventional air-to-ground targeting. However, new technology allows modern air defense systems to combine increased mobility with a minimal use of radar, reducing the number of targets available to Wild Weasel aircraft. Consequently, more of the operational load is shifted over to conventional air-to-ground assets, making the SEAD operation more sensitive to the typical error and delay sources in the conventional targeting process.

This thesis uses a low-resolution simulation model to evaluate the impact of information delay on a SEAD operation. The results show that the effectiveness of a SEAD operation is sensitive to information delay, but not to the anticipated degree. Not surprisingly, the dominating variable for the success of the SEAD operation is the number of allocated SEAD aircraft. Next, but an order of magnitude less influential, is the delay in the SEAD intelligence cycle. Finally, the frequency of movement of the air defense units seems to play a minor role.

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A SIMULATION ANALYSIS OF A SUPPRESSION OF ENEMY AIR DEFENSE (SEAD) OPERATION

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ABSTRACT

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THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases. Every effort has been made to ensure that the programs are free of computational and logical errors. Yet application of these programs without further verification is at the risk of the user.

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EXECUTIVE SUMMARY

Over the last two decades, Suppression of Enemy Air Defense (SEAD) operations have dominated surface-based air defense systems. Traditional SEAD operations rely on Wild Weasel aircraft equipped with Anti-Radiation Missiles (ARM). This combination of real-time target acquisition capability with high precision weaponry has rendered static surface-based radar systems vulnerable. As a result, SEAD operations are decoupled from the slow and error-prone intelligence gathering and evaluation process proceeding conventional air-to-ground targeting. However, new technology allows modern air defense systems to combine increased mobility with a minimal use of radar, reducing the number of targets available to Wild Weasel aircraft. As a consequence, more of the operational load is shifted over to conventional air-to-ground assets, making SEAD operation more sensitive to the typical error and delay sources in the conventional targeting process.

To evaluate the impact of information delay on a SEAD operation against a typical modern surface-based air defense system, a low-resolution simulation model is built combining Wild Weasel and conventional air-to-ground aircraft in attack of the air defense system. Furthermore, the sensitivity of the results with respect to the number of allocated SEAD aircraft and air defense mobility is evaluated.

The results show that the effectiveness of a SEAD operation is sensitive to information delay, but not to the anticipated degree. The relatively small effect of the delay can easily be explained; even if modern air defense systems can minimize the use of radar and benefit from increased mobility, they still depend on air surveillance radar to ensure a sufficient picture of the air situation. Consequently, Wild Weasel aircraft can still play a role, albeit to a lesser extent.

Not surprisingly, the results showed that the dominating variable for the success of the SEAD operation is the number of allocated SEAD aircraft. Next, but an order of magnitude less influential, is the delay in the SEAD intelligence cycle. Finally, the frequency of movement of the units seems to play a minor role. The latter result is as expected since the surveillance radar is still the most critical element in the air defense system, and the distances and speed of movement achieved by the radar units are not

large enough to create targeting difficulties for Wild Weasel aircraft enjoying very long detection range.

In conclusion, this thesis demonstrates how a small low-resolution simulation model can be used to quantify some of the trade-offs that must be made in the day-to-day planning of military operations. In general, military operations are influenced by factors that normally cannot accurately be estimated in advance. Still, the military decision making process requires that the effect of these factors are evaluated since they often are critical to making the necessary, and hopefully near optimal, decisions between possible courses of action. Until recently, the decision making process has been denied the use of computer models to support this requirement. The reason is that, traditionally, computer models have been too large and too complex to use for evaluating courses of actions within the allowed time frame. However, as this thesis demonstrates, a small low-resolution simulation model is well suited for this task since it is much easier to use and understand. Therefore, such models should become valuable tools in the typical ad-hoc analysis carried out in the decision making process.

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The author would like to take this opportunity to sincerely thank Professor Donald P. Gaver and Professor Patricia A. Jacobs for their patience and valuable guidance during the thesis work. Without their unwavering support, this thesis would not have been possible. Also, the author would like to acknowledge Major Arent Arntzen, Royal Norwegian Air Force, for the many hours of interesting and enlightening discussions about simulation modeling of air operations.

I. INTRODUCTION

A. ORGANIZATION OF THESIS

This thesis describes a setting wherein aircraft are tasked to destroy an enemy surface-based air defense system in what is known as Suppression of Enemy Air Defense (SEAD) operations. The overall purpose of the thesis is to evaluate how a new-generation of air defense systems currently being developed affects SEAD operations. The thesis is organized as follows:

- Chapter I discusses the background for the thesis and also states the specific questions the thesis answers.
- Chapter II describes the discrete-event simulation model that is used in the thesis. This includes a description of the scenario and also describes how some of the major event categories are implemented in the model.
- Chapter III provides an overview of the experimental design for the thesis. This includes a definition of the necessary independent variables and measures of effectiveness. The Chapter also describes how the simulation model was used to generate the necessary data.
- Chapters IV and V describe the results and conclusions of the research.

I have chosen not to include a listing of the JAVA code for the simulation model in this thesis. For the interested reader, a copy of the code is available from the author. Also, the code can be obtained from the Naval Postgraduate School by contacting one of the two thesis advisors.

We will begin by taking a closer look at the background.

B. BACKGROUND

Contemporary military campaigns increasingly rely on the use of air power. An important part of the air campaign is Suppression of Enemy Air Defense (SEAD) operations. The *Joint Tactics, Techniques and Procedures for Joint Suppression of Enemy Air Defenses (J-SEAD)* gives the formal definition of SEAD as "any activity that neutralizes, destroys, or temporarily degrades enemy surface-based air defenses by destructive and/or disruptive means" [Ref. 1]. The purpose of SEAD is to ensure a favorable air situation for the air campaign. Since 1980, the SEAD concept has established a dominance over a traditional surface-based air defense system. Two striking examples of this dominance are the SEAD operations by the Israeli Air Force in the Beka'a valley in 1982 [Ref. 2: p. 598-601] and the success of the Coalition SEAD forces in the Gulf War in 1991 [Ref. 3: p. 240]. In both cases, the SEAD forces faced a large integrated air defense system. The outcome of both operations was the virtual annihilation of the enemy air defense system with little or no damage to the SEAD forces. However, a new generation of advanced medium-range surface-to-air missile (SAM) systems is currently under development, and these systems are likely to challenge the SEAD dominance. The new systems incorporate technology that will increase both the effectiveness and survival rate of its units. Let's take a brief look at the new technology.

The major improvement with the new-generation air defense system is the introduction of a SAM with an onboard active radar seeker. A consequence of this new type of missile is that a dedicated target illumination radar is no longer needed. As a result, the total number of radars in the air defense system decreases. The elimination of the target illumination radar also has several other advantages. First of all, the illumination radar is a serious constraint on an air defense system's effectiveness since each system has only a limited number of these radars. Also, a system with an illumination radar has to launch each SAM sequentially and guide the missile all the way until it either hits or misses the target. On the other hand, a system with the new missile removes this constraint and has more simultaneous firepower. That is, several missiles can be fired at once compared to one at a time for a traditional system.

Another advantage of the new-generation air defense systems is that all units are mobile. The mobility together with the elimination of the illumination radar allows the air defense system to place the SAMs further apart. This broader positioning increases the air defense coverage and also reduces the probability of detection from enemy aircraft.

The detection probability decreases since a dispersed positioning of the air defense units presents the SEAD forces with fewer targets in the same area and thereby fewer detection cues.

The current SEAD operational concept focuses on the traditional air defense system's dependence on radar. The enemy radars are targeted in mainly two ways. First, the SEAD forces obtain valuable information about the enemy air defense system by detecting its radar emission with specialized intelligence assets (ELINT). Also, the radar emission is detected by specialized SEAD aircraft known as Wild Weasels. The *DOD Dictionary of Military and Associated Terms* defines a Wild Weasel as "an aircraft specially modified to identify, locate, and physically suppress or destroy ground based enemy air defense systems that employ sensors radiating electromagnetic energy." [Ref. 4] These aircraft can locate and attack the radars from a position well outside the enemy radar's detection range. According to the *Gulf War Air Power Survey Summary Report*, the Wild Weasel was the most effective SEAD asset in the Gulf War [Ref. 3: p. 229].

The new-generation air defense system with a limited number of radars presents a new challenge to the SEAD operation. The fewer number of emission sources forces the SEAD operation to collect more of the necessary intelligence with other intelligence assets. These intelligence assets have a more difficult task since it is quite difficult to detect ground targets with passive sensors. Similarly, fewer radars in the air defense system also mean there are fewer suitable targets for Wild Weasel missions. As a result, the SEAD operation must rely more on conventional aircraft to attack the air defense units. Conventional aircraft in this role have limitations since they are equipped with infrared and visual sensors. These sensors have limited detection ranges against small ground targets. Therefore, any inaccuracies in the intelligence data will seriously limit the aircraft's ability to find the assigned targets.

The *DOD Dictionary of Military and Associated Terms* defines intelligence as "the product resulting from the collection, processing, integration, analysis, evaluation, and interpretation of available information." [Ref. 4] Inaccurate intelligence can be induced in mainly two ways. First of all, the accuracy depends on the quality of the sensor observing the target. However, this is a problem of diminishing importance given the rapid progress of sensor technology. A more serious problem is the amount of time it takes from when a new target is first detected on the battlefield until a mission arrives in the target area. Traditionally, this time has been lengthy. The reason for the delay is that the "raw" target data have to go through the so-called intelligence cycle before the data become available to the users. The users in this case are the aircraft squadrons tasked to plan and execute the SEAD missions. The intelligence cycle is defined in the *DOD Dictionary of Military and Associated Terms* as "the steps by which information is converted into intelligence and made available to the users." [Ref. 4] The problem with the intelligence cycle is that modern sensor technology has dramatically increased the volume of available "raw" target data. However, the same increase in capability has not taken place in the intelligence organization tasked to convert the information into intelligence. As a result, the intelligence organization becomes unable to handle all of the target data and hence becomes a "bottleneck" in the overall process.

Another process that can also increase the delay time is the so-called targeting process. Targeting is defined in the *DOD Dictionary of Military and Associated Terms* as: "the process of selecting targets and matching the appropriate response to them, taking account of operational requirements and capabilities." [Ref. 4] In other words, targeting involves the selection of how and when to attack which target and also involves the coordination of all the necessary support for the missions. A successful outcome of the targeting process, of course, requires good intelligence. The outcome of the targeting process is disseminated to the users traditionally in the form of an Air Tasking Order (ATO). In a large and complex air operation, the targeting process can further increase the delay in the mission planning process and as such lead to even more inaccurate targeting data.

In summary, it is evident from the description given above that the time from the initial detection of a possible target until a SEAD mission reaches the target area can easily become long. A consequence of this is that with mobile targets the accuracy of the target data becomes questionable before the data are received by the users. Inaccurate targeting data have not been a major problem in traditional SEAD operations. In these operations, the Wild Weasel's long detection range against enemy radars tends to neutralize the effect of any inaccurate intelligence. However, the increased role of conventional aircraft means that the time used in the planning process becomes a critical factor for the effectiveness of the SEAD operation.

To reiterate the main points in this section: the new-generation air defense systems represent a formidable capability with a lot of firepower. Furthermore, a new-generation air defense system has only a limited number of surveillance radars and uses a dispersed positioning of its units. Consequently, the system is a very difficult target for a traditional SEAD operation. The new technology involved in the air defense system forces the SEAD concept to rely more on conventional aircraft. As a result, the SEAD operation becomes more sensitive to inaccurate target data. The preliminary conclusion to these factors must be that a new-generation air defense system combined with inaccurate target data will decrease the effectiveness of the SEAD operation unless compensatory actions by SEAD forces are devised and implemented.

C. PURPOSE OF THESIS

The thesis focuses on the effectiveness of a SEAD operation against a new-generation air defense system. The main problem is to analyze the effect of inaccurate target data caused by a delay in the intelligence cycle. The primary question of the thesis is

- **To what degree does a delay in the intelligence cycle impact the effectiveness of a SEAD operation against a new-generation surface-based air defense system?**

Two related questions will also be investigated:

- **To what degree does the effect of the delay change if the air defense units change positions more frequently?**
- **How does a change in the number of SEAD missions sent to attack the air defense system per day influence the SEAD operation's effectiveness, given the delay in the intelligence cycle?**

To answer these three questions, the use of a simulation model is necessary and this is the topic for the next chapter.

II. MODEL DESCRIPTION

A. SCENARIO

The purpose of the scenario is to provide a setting wherein the thesis questions can be addressed. The rest of this section gives an overview of a simplified scenario in which SEAD missions are tasked to attack a new-generation air defense system. Further details about how the scenario is used in the simulation model are described in the following sections in this chapter. Let's start with describing the air defense system.

The air defense scenario is based on the Norwegian Advanced Surface-to-Air Missile System (NASAMS). I chose the NASAMS since it is the first of the new-generation air defense systems to enter operational status in the world. Also, I have easy access to unclassified data about the system from sources in Norway. Appendix A gives a more detailed description of NASAMS capability and functionality. The version of the NASAMS used in this scenario has four categories of units as illustrated in Figure 1. These are

- Four air surveillance radars
- Four fire-distribution centers
- Nine medium-range SAM launchers
- Eighteen short-range weapons

The first three categories interact with each other and also comprise the medium-range capability of the system. This means that if all units in either of the first three categories are killed, no medium-range capability remains. Hence, the air defense system becomes inoperable from a SEAD perspective.

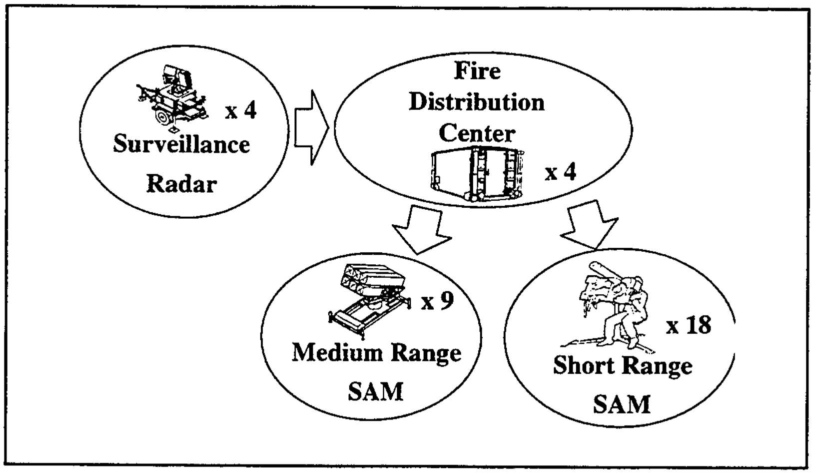

Figure 1. The Components of the Air Defense System

This air defense system is tasked to defend an area of 100 x 100 km. Initially, all units are spread out in positions that prioritize the areas closest to the front-line. This priority also means that if some of the air defense units closest to the front-line are killed, the system tries to maintain the priority by re-positioning the remaining units to forward areas. All units are mobile, but they need to be stationary to operate. Thus, the movement of the units is limited to moving from one operational position to the next. The next operational position is generally chosen at random within its assigned area. However, some limitations exist with regard to the choice. For instance, the radars, fire distribution centers and medium-range SAMs must be in a certain position relative to one another. The movement and positioning of air defense units are further discussed on page 13.

In this scenario, the air defense units are attacked by SEAD missions. All targets for the SEAD missions are chosen from the currently available intelligence. Many intelligence sources exist in a scenario like this. To avoid modeling each one, which is beyond the scope of this thesis, the intelligence collection process is modeled as a Poisson process supplying information at a certain rate. The incoming information is then delayed before being made available to the mission planning process. The scenario assumes that all collection sources know with certainty what type of unit they are observing and if the unit is operational or not. However, the position of the unit is known with error.

In the scenario, each SEAD mission is assigned two targets that are chosen in accordance with a target priority scheme. The scheme has three elements. The first element is that a number of potential targets are chosen based on a priority ordering of the different types of enemy air defense units. The priority order is 1) radars, 2) fire-distribution centers, and 3) medium-range SAM systems. Next, the scheme evaluates the time that has passed since the selected targets were last observed, and finally the scheme calculates the position of the targets relative to the expected front-line. The result is a target selection that enforces the priority ordering, but at the same time by using the most up-to-date intelligence, chooses the targets which are closest to the front-line. Further details about how the target priority scheme is implemented in the simulation model is described on page 18.

Also, the scenario uses a SEAD mission consisting of two pairs of aircraft. If one of the assigned targets is a radar, the mission has two Wild Weasel aircraft and two conventional aircraft. Conversely, if both the assigned targets are anything other than a radar, the mission consists of two pair of conventional aircraft. After being assigned targets, the mission takes off from a fixed base located 400 km from the operation area. The mission then flies toward the reported target location. If the mission detects one of the assigned targets and classifies it as the correct type, the target is attacked. The reported location of both the assigned targets must be investigated before the mission is allowed to attack other targets detected while underway. Note that while short-range weapon systems are not targeted as assigned targets, the SEAD missions are allowed to attack them as targets of opportunity. The mission will return to base for four reasons. These are

- Both assigned targets are investigated
- The mission runs out of weapons
- The mission has spent more than a specified time (1 hour) in the operation area
- The mission has lost a specified number of aircraft.

The description given above represents a simplified scenario, and a brief discussion of the simplification is necessary. The first major simplification is that all movement in the scenario is carried out in a straight line between way-points with the aircraft at a constant speed (500 kts) and at a fixed altitude (3 km). Also, all detection in the scenario will be handled through "cookie-cutter" calculations (see page 16 for details). Another major simplification is that the scenario includes only SEAD aircraft that attack air defense units. Hence, all other types of military units that play a role in the SEAD operation are omitted. The most important of these are the electronic warfare (EW) assets. EW units normally operate in support of SEAD missions. However, EW assets mainly protect the SEAD assets and are not intended to destroy the enemy air defense units. Also, the reduced number of radars in a new-generation air defense system will reduce the effectiveness of EW assets. The impact of omitting the EW will increase the attrition rate for the SEAD aircraft. Other major simplifications are that the scenario assumes perfect reliability for all active components and that the logistics system is omitted. A consequence of the last simplification is that the air defense system always has missiles available. However, even with these simplifications, the scenario is still sufficient as a setting for addressing the thesis questions.

In summary, the scenario is specifically designed to be as simple as possible, but at the same time sufficient to respond to the thesis questions stated in Chapter I. The described scenario is a simplified, but representative, situation that a SEAD operation may anticipate when attacking a new-generation air defense system. The scenario is realized in a discrete-event simulation model which is described in the next section.

B. SIMULATION MODEL

1. Model Selection

The purpose of a simulation model is to act as a generating tool for the necessary data for the thesis. Therefore, the aim of the modeling effort is to select a model that is as simple as possible, but at the same time ensures a sufficient level of detail. The choice is then either to use an existing model, or to develop a new model for the specific purpose. I began the modeling effort by looking at existing simulation models and evaluating these suitable for the particular modeling task. The main source of information was the computer reference system at the Dudley Knox Library of the Naval Postgraduate School.

Also, the *Catalog of Wargaming and Military Simulation Models* [Ref. 6.] was used in the search.

The search resulted in one appropriate model. This model is the Extended Air Defense Simulation (EADSIM). EADSIM is a system-level simulation model used to assess effectiveness of Theater Missile Defense (TMD) systems and the full spectrum of air defense systems. The model is a "many-on-many" simulation using both a discrete-event and time-step simulation approach. EADSIM can be used to model a variety of scenarios including SEAD and other air-to-ground operations. It is designed to evaluate the effectiveness of specific weapon systems against specific targets and to evaluate the value of different mixes of forces or resources. The model can accommodate any theater depending on the available terrain data. EADSIM separately models each unit (ship, aircraft, SAM, etc.) as well as the interactions between the units in the specified scenario. Even if EADSIM is primarily constructed for theater level simulations, smaller scenarios can be defined and executed. LCDR Neil R. Bourassa's Master of Science in Engineering Science thesis at Naval Postgraduate School in 1994 [Ref. 7] gives a thorough description of the EADSIM model.

The EADSIM model has two main weaknesses for the specific modeling task. The first is that EADSIM is a very large and complex model (300,000 lines of code in 1993). This implies that learning how to use the model and setting up the specific scenario, as described above, would take much time. The second weakness is that EADSIM needs a lot of high-resolution input data. This means that a large amount of data is needed to create the specific scenario, data not necessarily available to international students. The combination of the two factors lead to my developing a low-resolution simulation model specifically for the described scenario. It may well be an efficient modeling tactic to study options first, quickly, using a low-resolution model, and then fine tuning the results, perhaps using EADSIM.

2. Simulation Model Structure

The simulation model is developed in the JAVA programming language (version 1.1.6). The model is a discrete-event simulation model using the Simkit package for all event handling. Simkit is a JAVA package specifically constructed for discrete-event simulations and was originally constructed by Lt. Kirk A. Stork as a part of his Master of Science in Operations Research thesis at the Naval Postgraduate School in 1996. Since then, Simkit has been maintained and expanded by Prof. Arnold Buss of the Naval Postgraduate School. A detailed description of Simkit is given in Lt. K. Stork's thesis [Ref. 8] and in the *Simkit User Manual* [Ref. 9]. The rest of this section gives an overview of the structure of the simulation model.

The simulation model uses a three-dimensional Cartesian coordinate system on a kilometer scale. The time scale in the model is minutes. The scales are chosen because they offer a compromise between the high speed of the aircraft and the slow speed of the air defense units. As a result, the chances of a possible problem with machine round-off errors are reduced. The model is divided into three modules. These are

- The Air Defense module
- The SEAD module
- The Interaction module

The Air Defense module controls the four air surveillance radars, four fire-distribution centers, nine medium-range SAM launchers, and eighteen short-range SAMs. The responsibility of the module is to control how these air defense units operate. This task includes several event categories such as:

- The positioning of the air defense units
- The movement of the air defense units
- The tracking of detected SEAD missions
- The threat evaluation of tracked SEAD missions
- The engagement of the SEAD missions

A description of the event categories are given in the next section.

The SEAD module is responsible for generating and executing the SEAD missions. To do this, the module has three components. These are

- A SEAD intelligence organization
- A SEAD mission generator
- The SEAD missions themselves.

The intelligence organization receives target data from the Poisson process in the Interaction module. The rate of the Poisson process is an input parameter to the model. Before the data can be used in the mission generation process, they are delayed for a specified amount of time. The length of the delay is also an input parameter and hence is controlled by the user. The sortie generator creates the SEAD missions in accordance with a mission generation rate which is also an input parameter to the model. The generation process includes choosing an appropriate target set from the available intelligence and deciding the composition of the mission accordingly. Finally, the SEAD module is responsible for the execution of the SEAD missions.

The Interaction module is responsible for all interaction between the air defense units and the SEAD missions. To make this possible, the Interaction module has a reference to all air defense units and to all active SEAD missions. The relationship between the Interaction module and the two other modules is illustrated in Figure 2.

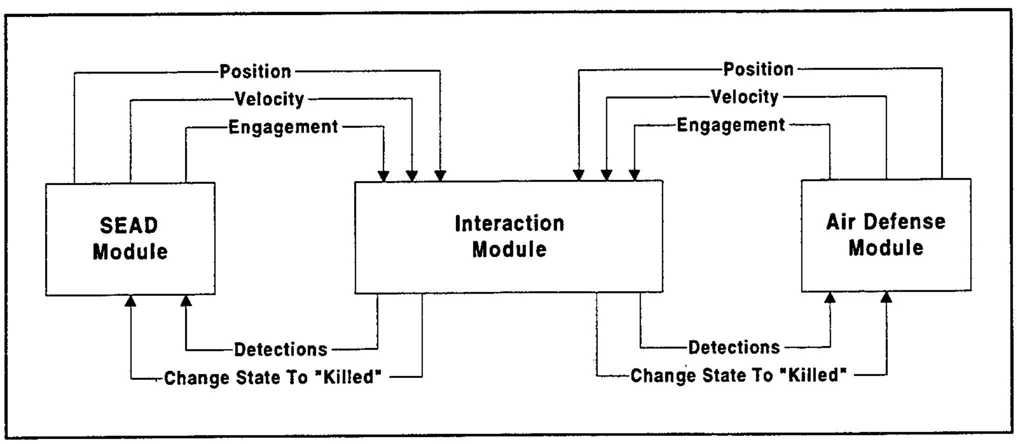

Figure 2. The Layout of the Simulation Model

3. Model Assumptions

Any model is a simplification of the reality. It is therefore important to understand how the present model is constructed, and what assumptions it makes. This section is therefore devoted to describing the events and processes that constitute the majority of the assumptions made in the model.

a. Movement Events

All movement events are handled internally in the SEAD module for the SEAD missions and in the Air Defense modules for the air defense units. However, whenever a unit changes position or velocity, the unit will automatically notify the Interaction module. Let's start with the movement events in the Air Defense module.

As stated in the scenario description, the air defense system prioritizes the area closest to the front-line. To represent this priority, the model divides the air defense operation area into four zones as shown in Figure 3. Each zone number represents the priority of the zone.

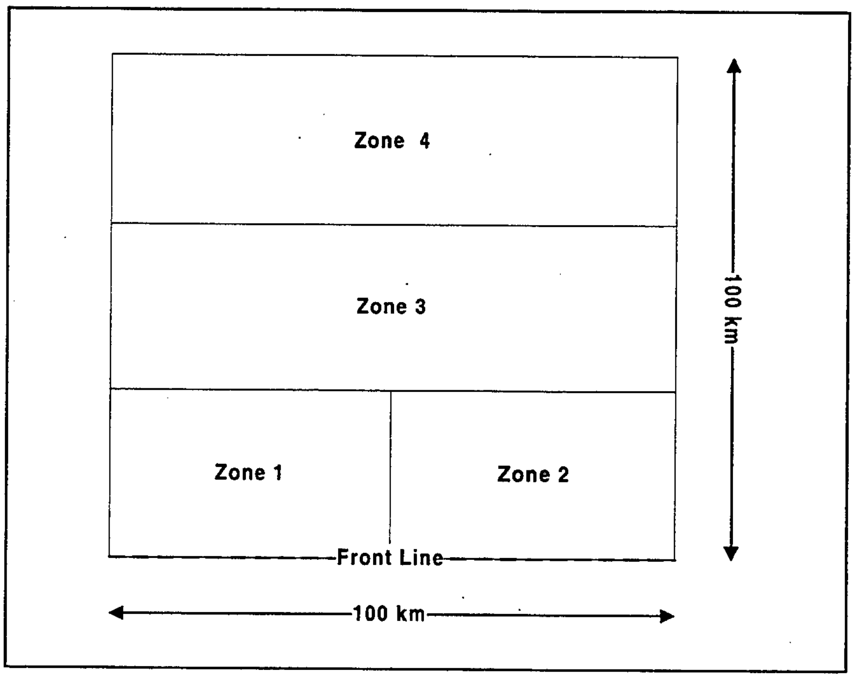

Figure 3. The Air Defense Operation Area

Initially, the model distributes the available air defense units as shown in Table 1. The position of each unit within a zone is chosen at random with the limitations described on the next page.

	Number of Units			
Zone	**Radars**	**Fire-Distribution Centers**	**Medium-range SAM**	**Short-range Weapon Systems**
1	1	1	3	4
2	1	1	3	4
3	1	1	2	5
4	1	1	1	5
Total	4	4	9	18

Table 1. Initial Positioning of the Air Defense Units

The model moves the air defense units in accordance with a specified movement frequency (an input parameter to the model) and only one unit in each category is allowed to move at a time. The movement frequency is defined as the number of movements per unit per day. The model schedules all movements sequentially. In general, the time between movements (T) are decided by the formula given in Equation 1 where 1440 is the number of minutes in a day, N is the number of operational air defense units in particular category, and MF is the specified movement frequency.

$$T = \frac{1440}{N \cdot MF} \tag{1}$$

All movement takes place in a straight line and with a constant speed (40 km/h). As a rule, the unit that has stayed in the same position for the longest time moves first. However, units that have survived an attack from a SEAD mission are given priority. When a unit is ordered to move, the next position is chosen at random within the zone to which it belongs. The only exception is that the radars and the medium-range SAM launchers must be within a specific distance from the fire-distribution center in the same zone (radar = 50 m, medium-range SAM = 25 km). Consequently, the radars and the medium-range SAM launchers must move with the fire-distribution center to keep their relative position. Thus, in this case more than one unit of each category moves simultaneously. In general, all units stay in the zone to which they are initially assigned. However, if air defense units in the zones closest to the front-line are killed by the SEAD missions, units from the "rear" zones are moved forward to maintain the priority of the areas closest to the front-line.

The SEAD missions also move in a straight line between way-points. The aircraft fly at a fixed altitude (3 km) and with a constant speed (500 kts). The SEAD missions are generated sequentially in accordance with a specified mission generation rate (an input parameter). After takeoff, all missions fly to an initial way-point located 100 km south of the air defense operation area. At this point, the mission extracts the reported position of the first of the assigned targets from the intelligence data and sets course correspondingly. If a target is detected in the vicinity of the reported target location, the mission changes course to come within weapon range as soon as possible. The new course is radial towards the target location and is held until the weapon is launched. After the weapon is launched, the mission sets course for the reported location of the second assigned target. There, the same evaluation happens again, and after either an attack or an unsuccessful investigation of the reported target location, the mission sets course for the home base. During the egress from the air defense operational area, the mission can deviate from the course and attack targets of opportunity.

b. Detection Events

The model represents four different sensors. All these sensors are of a modified "cookie-cutter" type. Alan R. Washburn states in *Search and Detection* that "the sensor is of a cookie-cutter or definite range type, by which is meant that there is a fixed range *R* such that the target will be detected at the first moment when its distance from the searcher is smaller than *R*." [Ref. 10: p. 1-1] The modification to the "cookie-cutter" is different for all four sensor types and each modification is described individually.

The first sensor is the ESM sensor of the Wild Weasel aircraft. This sensor can only detect emissions from enemy air surveillance radars. The modification to the "cookie-cutter" calculation is that the ESM sensor uses a range that is the enemy air surveillance radar's maximum detection range multiplied with an adjustable factor generally greater than one. This thesis has the adjusting factor fixed to 1.1.

Consequently, the Wild Weasel aircraft equipped with the ESM sensor will always detect an enemy radar before the aircraft enters the radar's detection range.

The second sensor is the sensor onboard the conventional aircraft. This sensor has a maximum detection range of 6 km. Hence, an aircraft flying at a fixed altitude of 3 km has a horizontal detection range of approximately 5 km. The modification to the cookie-cutter is that when a target enters the detection range, the model evaluates a probability of detection. The probability of detection is specified by a "signature value" given to each of the enemy air defense units. This signature value is set in accordance with the size and the signature of the unit. The value is modified each time the air defense unit changes state (starts to move, fires a missile, etc.). The evaluation of the probability, namely, the realization (or not) of a detection, uses a draw from a uniform (0,1) distribution and compares this value to the current signature value of the air defense unit in question. If the draw is smaller than the signature value, the target is immediately detected. If not, the sensor doesn't detect the target. Note that the sensor repeats the evaluation if the air defense unit changes state (and thereby signature value) while inside the sensor's maximum detection range.

The third sensor is the air surveillance radar in the air defense system. The detection calculation for this sensor also uses a "signature value" given to each SEAD mission. This signature value is set before the mission takes off and is a draw from a uniform (0.3, 0.8) distribution. However, this signature value is not used as a probability of detection for the air surveillance radar. Instead, it is used to modify the radar's detection range (75 km * signature value). As a result, the radar always detects a SEAD mission that comes within the modified detection range.

The last sensor is the sensor of the short-range weapon systems. This sensor is a "pure" cookie-cutter with a range that is the same as the weapon engagement range (7 km).

c. *Engagement Events*

In general, the engagements for both the SEAD missions and the air defense system are handled the same way. The engagement begins with a decision to engage. This decision is based only on the target's relative position to the attacker and the engagement event is scheduled the moment the target comes within the maximum weapon engagement range. However, a SEAD mission is not allowed to engage targets of opportunity before it has attacked or investigated the reported locations of the targets assigned to it. Four different weapon types are modeled. These are

- An anti-radiation missile carried on the Wild Weasel aircraft which can only be used to attack radars that are emitting (range = 50 km).
- An air-to-ground missile carried on the conventional aircraft that can be used to attack all types of air defense units (range = 10 km).
- A medium-range surface-to-air missile (range = 15 km).
- A short-range surface-to-air missile (range = 7 km).

Each weapon has an associated hit probability that is drawn from a uniform (0.4, 0.9) distribution and a "maximum miss distance to kill" that is fixed at 10 m. Also, all weapons are modeled with a constant speed of approximately 0.8 Mach.

The engagement starts when a weapon is launched. At this time the firing unit sends an engagement message to the Interaction module. The Interaction module calculates when the weapon will reach the target position. At this time, an engagement evaluation will occur. The outcome of the engagement is evaluated by drawing a value from a uniform$(0,x)$ distribution where the value x is calculated by dividing the maximum miss distance with the weapon's hit probability. The resulting value represents the distance from the target to the weapon's closest point of approach (CPA). The Interaction module then compares the calculated distance to the maximum miss distance and decides if the target is killed or not. It is killed if the calculated distance is shorter than the maximum miss distance, otherwise not.

d. Poisson Process

The role of the Poisson process is to control the flow of intelligence into the SEAD mission planning process. The process is implemented in the Interaction module and thus has a reference to all of the air defense units. The rate of the Poisson process is an input parameter to the model. However, the model does not simulate the impact of an insufficient intelligence flow. As a result, the rate must be set high enough to ensure that a sufficient amount of intelligence data exists in the SEAD mission planning process. At the time of an intelligence message, the process chooses (with replacement) one of the air defense units at random and forms an intelligence message. Note that the Poisson process does not distinguish between alive or killed air defense units. This aspect is handled in the SEAD module where only alive targets are entered into the intelligence cycle. The intelligence message contains the following information:

- The type of air defense unit
- The location of the air defense unit implemented with a bivariate normal target location error (standard deviation of 250 m)
- The state of the air defense unit (moving, emitting, etc.)
- If the target is alive or killed.

The resulting intelligence message is sent directly to the SEAD module where it enters the intelligence cycle. The Poisson process is implemented with its own random number stream. The process starts with the same seed at each run. As a result, the Poisson process supplies the SEAD module with intelligence messages in the same order in each run.

e. Target Priority Scheme

The target priority scheme is responsible for choosing the target set that is assigned to a SEAD mission. The scheme has three elements as described on page 9 and is implemented in the SEAD module in the following way. First, the model chooses four targets from the currently available intelligence (intelligence messages older than 24 hours are discarded). The choice is based on a target priority ordering. The ordering is 1) radars, 2) fire-distribution centers and 3) medium-range SAM launchers. Next, the model eliminates the one target with the longest time since it was last observed. Finally, the two targets located closest to the front-line are chosen and assigned to the SEAD mission. Note that the target priority scheme depends on a sufficiently high rate of the Poisson process. This is necessary to ensure that the scheme has enough intelligence data to choose from.

This concludes the brief description of the major assumptions the model makes. The next topic is the necessary input to the model.

4. Model Input

The current version of the model lacks a Graphical User Interface (GUI). As a result, all input parameters must be set directly in the code. The necessary input parameters to the model are of two categories. The first category is the list of independent variables as described in Chapter III and the second is a list of necessary simulation parameters. The resulting parameters are listed in Table 2.

Independent Variables	Simulation Parameters
• The delay in the SEAD mission planning process • The movement frequency of the air defense units • The mission generation rate of the SEAD missions	• The rate of the Poisson process • The number of days for the SEAD operation • The number of replications for each variable combination

Table 2. The Input Parameters to the Simulation Model

5. Model Output

The model provides output in the form of six lists. These record at the end of each day. Each list has one column for each day and one row for each replication. The lists are

- The total number of radars alive
- The total number of fire-distribution centers alive
- The total number of medium-range SAM launchers alive
- The total number of short-range SAMs alive
- The total number of SEAD aircraft killed during the day (the cumulative sum can be found by adding the number for each day)
- A list which states if the air defense system retains medium capability or not.

The last list contains a binary value. The value one signifies that the air defense system retains medium-range capability at the end of the particular day. The value zero signifies that the air defense system has lost all of its medium-range capability. The medium range capability of the air defense system is explained on page 7. An example of the output is given in Appendix B.

This concludes the description of the simulation model. The next topic is the experimental design and how the model was used to generate the necessary data.

III. EXPERIMENTAL DESIGN AND DATA GENERATION

A. INDEPENDENT VARIABLES

A combat scenario, of course, involves a large number of variables that influence the operation. The problem is then to establish the factors that can be used as independent variables in the specific analysis. All other variables need to be handled in a consistent manner. The thesis omits a lot of variables by using a simulation model with a limited scenario as described above. All variables not identified as independent variables are either held at a fixed value or are drawn from a specified probability distribution.

The thesis considers three independent variables. The independent variables are chosen because they are related to the effectiveness of the SEAD operation and to the specific thesis questions stated on page 5. The rest of this section describes the three variables and how they relate to the thesis questions.

1. The Delay Time in the Intelligence Cycle

The main thesis question is related to the delay time in the intelligence cycle. The delay time is therefore used as the first independent variable. The delay time is defined as the time that elapses from a moment at which a target is observed on the battlefield by an intelligence asset until the evaluated target data becomes available as intelligence to the mission planning process. A range from zero to ten hours will be investigated.

2. The Movement Frequency of the Air Defense Units

The relationship between the delay in the intelligence cycle and the effectiveness of the SEAD operation is dependent on how often and how far the air defense units move. For example, with a high movement rate of the air defense units, it is more likely that a unit has moved before a SEAD mission reaches the target area. As a result, one should expect to see a reduced effectiveness of the SEAD operation. However, this effect is dependent on the length of the delay in the intelligence cycle and must be expected to increase if the delay is large. Therefore, the second independent variable is the movement frequency of the air defense units. The movement frequency is defined as the number of movements per unit per day. Note that this variable only regulates the rate of movement. The distance a unit moves is in general chosen at random as described on page 15. The thesis will investigate the movement frequency over a range from one to four movements per day.

3. The SEAD Mission Generation Rate

The mission generation rate is defined as the number of SEAD missions executed per day. This rate, combined with the fact that the scenario always uses four aircraft per mission, controls the number of aircraft devoted to the SEAD operation each day. This variable is necessary to answer the third thesis question (see page 5). The thesis will vary the mission generation rate over a range from one to four missions per day.

This concludes the description of the independent variables and the next topic is how we measure their impact on the effectiveness of the SEAD operation. This is commonly referred to as Measures of Effectiveness, the topic for the next section.

B. MEASURES OF EFFECTIVENESS

Daniel H. Wagner and W. Charles Mylander in their *Naval Operations Analysis* define Measure of Effectiveness as " an assignment of values to courses of action." They further describe the role of the MOE as:

> Much of the role of an MOE is as a quantitative proxy or surrogate for the objective. An MOE, then, must be closely related to the objectives of the operation. [Ref. 5]

This means that a possible MOE should be related to the overall goal of the SEAD operation, namely, to ensure a friendly air situation for the other air assets operating in the same area. The *Gulf War Air Power Survey Summary Report* suggests a suitable MOE for this situation. It states:

> From an operational standpoint, the relevant measure of effectiveness against Iraq's ground-based air-defense system was not the SOCs, IOCs, or missile-firing batteries physically destroyed but the numbers of Coalition aircraft that were *not* shot down or damaged while carrying out their missions over Iraq and the Kuwait theater of operations (emphasis in original). [Ref. 4: p. 60]

The quote indicates that the effectiveness of the SEAD operation should be measured by the success or attrition rate of the other air assets operating in the same area. However, such a MOE demands a simulation model incorporating the entire air campaign and the scope of such a model is beyond the range of this thesis.

Instead, the thesis uses one main MOE based on the attrition of the enemy air defense system. The MOE is *the probability that the enemy air defense system has lost its medium-range capability conditional on the value of the independent variables.* The probability is estimated from a count of the number of operational air defense units in each category at the end of each day. In addition, to address the two secondary thesis questions as stated in Chapter I, it is necessary to estimate the distributions of the total number of units killed in each category. This includes all air defense categories, and also the number of killed SEAD aircraft.

The next section takes a closer look at how the simulation model is used to generate the necessary data for the thesis.

C. DATA GENERATION

The thesis has three independent variables that take on a finite number of values. The values are

- Zero-, five- and ten-hour delay times in the intelligence cycle
- One to four movements per air defense unit per day

- One to four SEAD missions generated per day

The result is a total of forty-eight variable combinations.

Each of the other input parameters to the model as described on page 19, are held at a fixed value. These values are

Rate of Poisson Process	11 (per day)
Number of days for the SEAD operation	7 days
Number of replications	300

Table 3. Input Parameters to the Simulation Model

The simulation is run for three hundred replications for each combination of values of the independent variables. Three hundred replications was chosen after investigating the number of replications necessary to ensure sufficiently small standard errors. The resulting standard errors can be found in Appendix C.

The runtime of the model is highly dependent on the variable combination. This is because the number of events that must be executed in the model grows rapidly with an increase in the movement frequency or the mission generation rate. The resulting runtime for a specific variable combination with three hundred replications varied from twenty to fifty-five minutes using a PC with a 266 MHz processor and 144 MB of RAM.

This concludes the summarized description of the experimental design and how the data are generated. At this point, we can start examining the results from the model runs.

IV. RESULTS

A. CHAPTER ORGANIZATION

The purpose of this chapter is to present a statistical analysis of the data generated from the simulation model. The chapter studies the data in the context of the three thesis questions. To reiterate, the thesis questions are

- To what degree does a delay in the intelligence cycle impact the effectiveness of a SEAD operation against a new-generation surface-based air defense system?
- To what degree does the effect of the delay change if the air defense units change positions more frequently?
- How does a change in the number of SEAD missions sent to attack the air defense system per day influence the SEAD operation's effectiveness, given the delay in the intelligence cycle?

The discussion of the results begins with describing the data with respect to the Measure of Effectiveness (MOE) defined on page 24 as *the probability that the enemy air defense system has lost its medium-range capability, conditional on the values of the independent variables*. Next, the distribution of the total number of SEAD aircraft killed by the end of day seven is examined, and finally, the chapter investigates the distributions of the total number of air defense units killed by the end of day seven in each category. Summary statistics for the MOE and the distributions are given in Appendix C. All data analysis was carried out using the S+ statistical computer program (version 4.5) [Ref. 11].

The chapter uses standard statistical techniques, such as sample means, standard errors and confidence intervals to determine if the output from the simulation model can provide statistically significant answers to the thesis questions. I have chosen to use a non-parametric bootstrap to estimate the percentage intervals of the *bias-corrected and accelerated* (BC_a) type for the sample means. An excellent description of the bootstrap technique and the BC_a percentage intervals is given in Efron and Tibshrihani, *An Introduction to the Bootstrap* [Ref. 12: p. 184].

The rest of this chapter will frequently refer to the independent variables defined in Chapter III. Therefore, I will use an abbreviated form of the variable names as shown in Table 4.

Independent Variable	Abbreviation
"The delay time in the SEAD intelligence cycle"	Delay
"The movement frequency of the air defense units"	MF
"The SEAD mission generation rate"	MGR

Table 4. Abbreviations for the Independent Variables

B. EVALUATION OF THE MEASURE OF EFFECTIVENESS

The Measure of Effectiveness (MOE) is estimated from one of the output lists described in Chapter III with one list generated for each of the forty-eight combinations of the independent variables. The combinations are listed on page 25. The list is in a form of a matrix with one column for each day in the seven-day period, and one row for each of the three hundred replications. The elements in the matrix are binary values indicating if the air defense system retains medium range capability at the end of the day (the element is one) or not (the element is zero). The value of each element is calculated as described on page 21.

The columns in the matrix can be regarded as 300 Bernoulli trials. Hence, each day in the period has a binomial distribution with number of trials, n = 300, and the probability of success, the probability the enemy air defense system has lost its medium range capability at or before the end of the day. The MOE is estimated by the fraction of replications where all medium range capability in the air defense system is destroyed. The formula for the estimation is given in Equation 2.

$$MOE = \frac{\sum_{i=1}^{n}(1 - X_i)}{n} \qquad (2)$$

In Equation 2, X_i is the binary value as described above and n is the number of replications ($n = 300$). The $1 - X_i$ term is necessary because X_i equals one if the air defense system retains its medium-range capability at the end of the day. Since we want to measure the opposite effect, the binary value must be reversed.

1. Initial look at the MOE

Figure 4 shows how the MOE develops over the seven-day period for twelve of the combinations of independent variables.

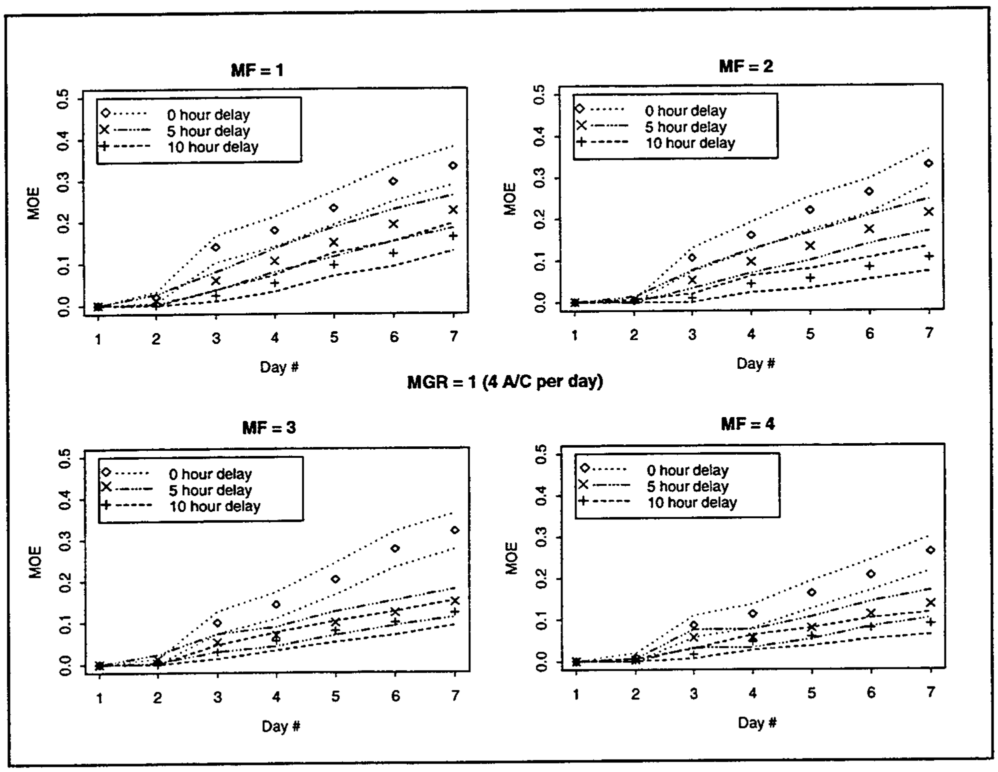

Figure 4. Plot of how the MOE develops over the seven-day period

Each panel shows three variable combinations where only the Delay variable is changing. The MF and MGR variables are held constant. The dotted lines in the plots are the 90% BC_a percentile interval for the estimated MOE. All panels have a common MGR = 1. However, the MF variable is different in each panel with a MF = 1 in the upper left-hand panel and MF = 4 in the lower right-hand panel.

Figure 4 indicates that there is a consistent effect of the Delay variable since the combinations with the lowest setting of the Delay variable have invariably a larger estimated probability in all four panels. This pattern holds for all forty-eight variable combinations. Also, the percentile intervals indicate that in most cases the difference in the estimated probability due to a change in the Delay variable is statistically significant. Because of the consistent pattern, the rest of this section will only deal with the MOE at the end of the seven-day period.

The Trellis Graphics Library in S+ [Ref. 11: p. 207] offers a possibility to view all forty-eight variable combinations in one graph. This is shown in Figure 5 as a bar-chart which plots the estimated MOE at the end of the seven-day period for each of the forty-eight combinations of the independent variables. A summary of the data used to create Figure 5 is given in Appendix C. Before discussing what the figure shows, it is necessary to describe briefly how to read this figure.

The graph has a total of sixteen panels organized in four columns and four rows. The x-axis in each panel represents the estimated probability (the MOE) at the end of the seven-day period. Each panel has the MF and MGR variables at a constant value and has three horizontal bars representing the three possible values of the Delay variable. The lower bar has a delay of zero hours, the middle bar five hours, and the upper bar ten hours. Also, each bar has an associated black line drawn at the end. This line indicates the 90% BC_a percentile interval for the estimated MOE.

Above each panel are two bands, each with an abbreviated variable name and a tick-mark. The value of the variable in each band can be read from the position of the corresponding tick-mark. Both the MF and MGR variable can take on values from one to four. Consequently, the bands have the values of the two variables equal to one if the tick-mark is on the extreme left side of the band, and increasing to a value equal to four if the tick-mark is on the extreme right side of the band. The MF variable is held constant in each column and the MGR is held constant in each row. In other words, the MF is starting at one movement per unit per day in the lower row (tick-mark to the left), and ending up at four movements per unit per day in the upper row (tick-mark to the right). Likewise, the MGR is one SEAD mission per day in the left column and ends up at four

SEAD missions per day in the right column. As a result, one can get an indication of the effect of changing the MF variable by reading left to right across the row and an indication of the effect of changing the MGR variable reading up or down each column.

An indication of the statistical significance level can be seen from the percentage intervals drawn at the end of each bar. If for a particular bar, the percentile interval does not overlap the end of an adjacent bar, this indicates that the difference between the two bars is statistically significant. Exact values for the percentile intervals are given in Appendix C.

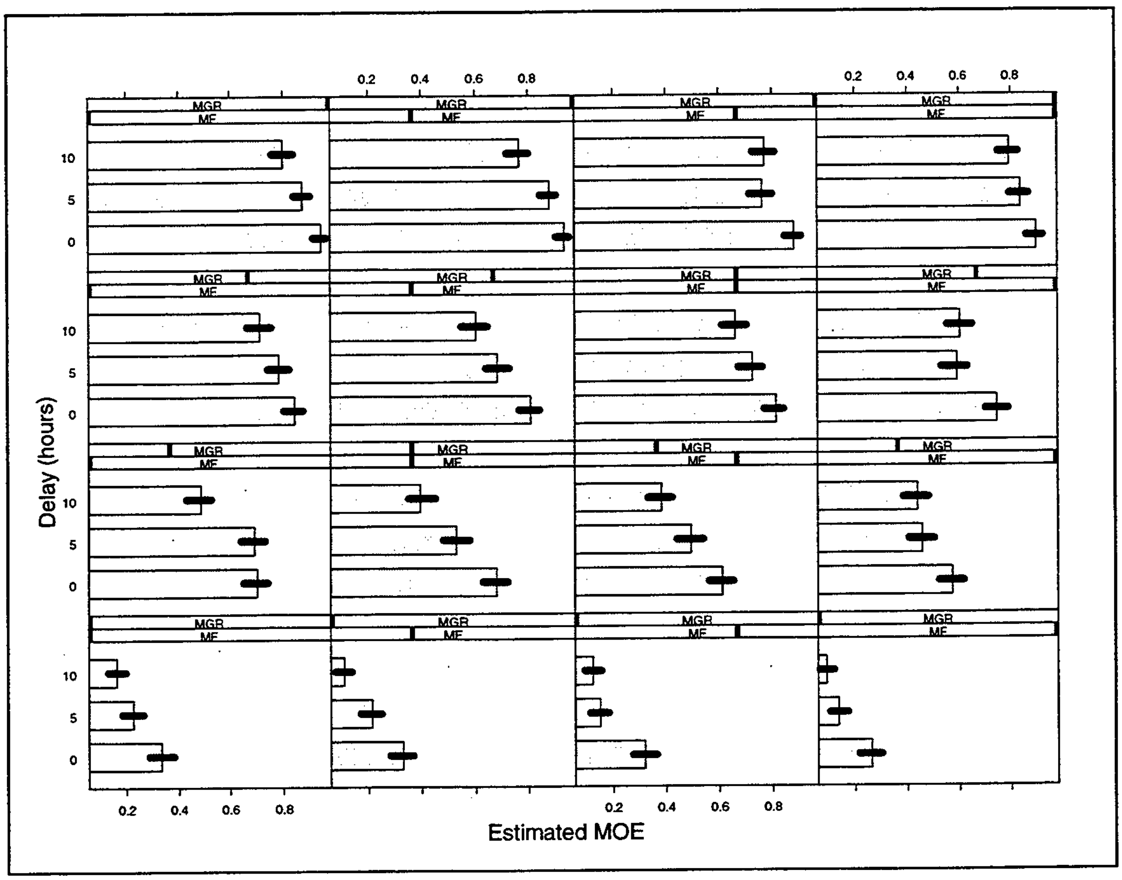

Figure 5. Trellis bar-chart of the estimated MOE at the End of Day Seven

Each panel in Figure 5 shows the effect of the Delay variable on the MOE where the two other variables are held at a constant value. The panels indicate that there is a consistent effect of increasing Delay over almost all forty-eight variable combinations. The pattern is that in almost all panels, the bars at the top of the panel are shorter than the bar at the bottom of a panel. Only five panels indicate a situation where two or more bars have an approximately equal length. However, no relationship is obvious between the variable settings for these five panels, and the lack of significance is probably due to randomness in the simulation model. The relationship between the Delay and the MOE is that the MOE decreases with an increase in the Delay time.

The effect of the MF variable can be found from reading the figure left to right along the rows. As can be seen, the effect of the MF variable is less than that of the Delay variable. The MF variable has at best only a modest effect, with the MOE decreasing when the movement frequency increases.

The columns of the figure show the effect of the MGR variable. This variable has an obvious effect on the MOE, with the estimated probability increasing when the mission generation rate increases.

To summarize the discussion, Figure 5 shows that all three independent variables have an effect on the estimated probability. The observed relationship between the three variables and the MOE is that the MOE increases with an increasing SEAD mission generation rate. However, the MOE decreases with both an increase in the delay time in the intelligence cycle, and with an increase in the movement frequency of the air defense units. Of the three independent variables, MGR is clearly the most influential.

To further summarize the observations, the next section fits a Logistic Regression model to the same data used to produce Figure 5.

2. Logistic Regression Model

The purpose of fitting a Logistic Regression model to the output from the simulation is to create a tool with an easy mathematical form that can be used to summarize the observations from the runs of the simulation model. Thus, the intended use of the regression model is *not* to predict the outcome of the SEAD operation, but only to act as a summary tool.

A Logistic Regression model is a generalized linear regression model where the response variable is transformed using a so-called "logit" transformation. The logit-transformation is given in Equation 3. A Logistic Regression model assumes that the logit of the response variable can be expressed as a linear combination of a number of explanatory variables. The logit-model in this thesis has the probability that no medium-range air defense capability remains at the end of the seven-day period (the MOE) as response variable.

$$\log\left(\frac{MOE}{1-MOE}\right) = const_0 + const_1\cdot(Delay) + const_2\cdot(MF) + const_3\cdot(MGR) \quad (3)$$

A logit model was fitted to the 14400 binary observations (48 variable combinations x 300 replications) with the independent variables as explanatory variables (regressors). The fitting process was done using a step-wise regression procedure as described by Ryan [Ref. 14: p. 270]. The S+ statistical program has a function that automates this procedure [Ref. 11].

The step-wise fitting process resulted in a model where all three independent variable are included. However, several diagnostic plots indicated that the MGR variable needed a log-transformation. The resulting regression model on the logit scale is given in Equation 4.

$$\begin{array}{lcccccccc} logit(MOE) & = & -0.515 & - & 0.096\cdot Delay & - & 0.168\cdot MF & + & 2.24\cdot\log(MGR) \\ & & (0.06) & & (0.005) & & (0.018) & & (0.04) \end{array} \quad (4)$$

The numbers given in parentheses under the model equation are the estimated standard errors (SE) for the corresponding coefficients.

The significance level of the coefficients was investigated using a confidence interval suggested by Ryan [Ref. 14: p. 272]. He states that an approximate confidence interval for the coefficients is given as $\beta_i \pm z_{\alpha/2}s_{\beta i}$ where β_i is the estimated coefficient for the i^{th} explanatory variable, $z_{\alpha/2}$ denotes the standard normal deviate and $s_{\beta i}$ is the estimated standard error of the estimated coefficient. The resulting confidence intervals are given in Table 5. These confidence intervals are only asymptotically correct [Ref. 14: p. 272]. A better approximation can be obtained using a bootstrap procedure explained in

Efron and Tibshirani [Ref. 11: p. 153]. However, because of the large sample size, the approximate confidence intervals are used and should be a good approximation.

Explanatory Variable	Lower Confidence Limit	Upper Confidence Limit
Intercept	- 0.613	- 0.416
Delay	- 0.105	- 0.089
MF	- 0.197	- 0.139
Log (MGR)	2.175	2.311

Table 5. 90% Confidence Intervals for the Explanatory Variables

As we can see from the table, no confidence interval includes zero and we can conclude that the coefficients are all statistically different from zero.

The "goodness of fit" of the model was further investigated using several different diagnostics plots as described by Ryan [Ref. 14: p. 287]. Only two of these are given here. Figure 6 shows a plot of the MOE estimated with the logit-model vs. the MOE estimated as the number of replications in which there is no medium-range capability at the end of day seven. The figure uses the probability scale. Figure 6 is constructed using the logistic regression model to estimate the MOE for the original forty-eight combinations of independent variables. These values are plotted against the values estimated directly from the simulation data (maximum likelihood estimate of the binomial p).

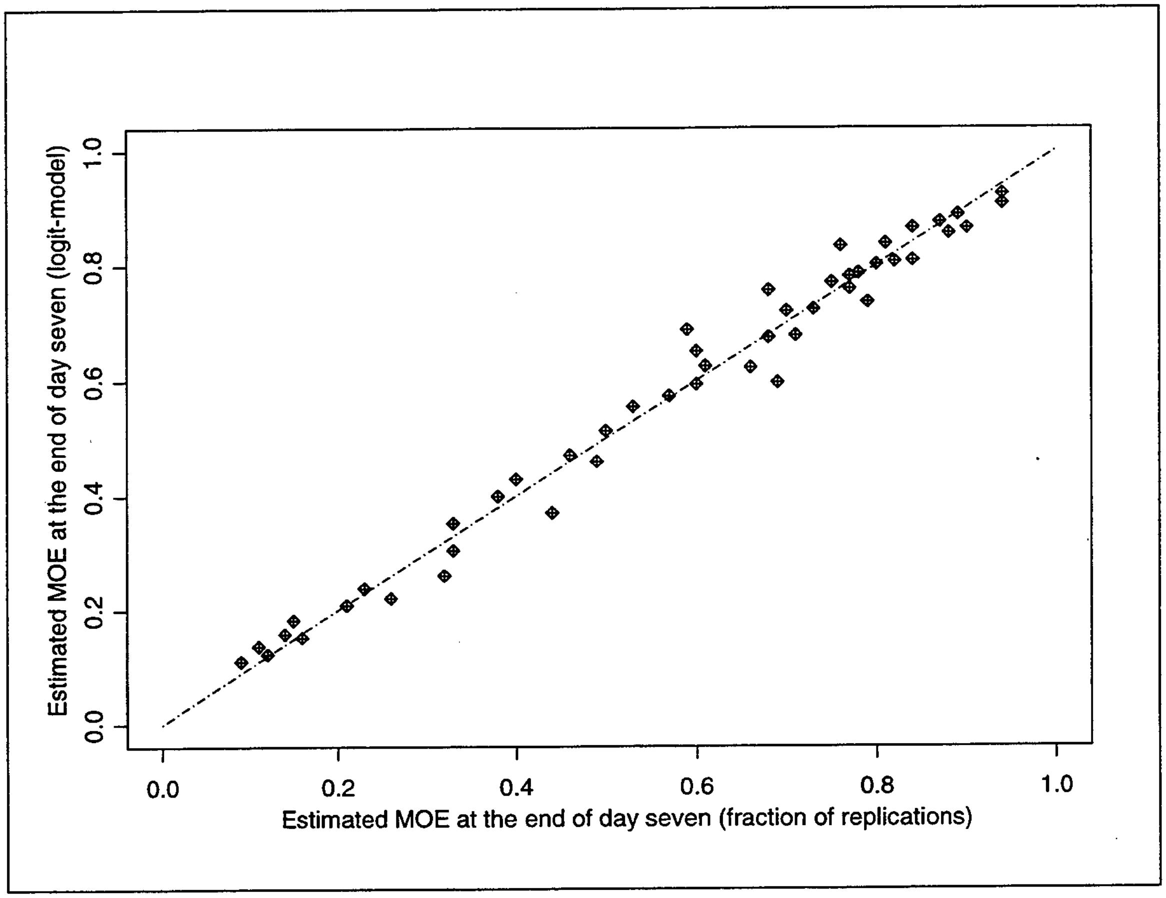

Figure 6. Plot of the MOE estimated from the logit-model vs. the MOE estimated by from the number of replications at the end of the seven-day period

As we can see, the points fall very close to a forty-five degree line and no systematic behavior of the points is obvious. This indicates that the logit-model fits the data reasonably well.

The second diagnostic plot is a partial residual deviance plot for each of the three explanatory variables on the logit scale as shown in Figure 7.

Figure 7 shows each explanatory variable plotted against the fitted terms on the logit scale. Also, the plots include the upper and lower "twice-standard-error" curves for the fitted terms (dotted lines) and the partial deviance residuals (circles). The slope of line of fitted terms in each plot also indicates the relative effect of each variable.

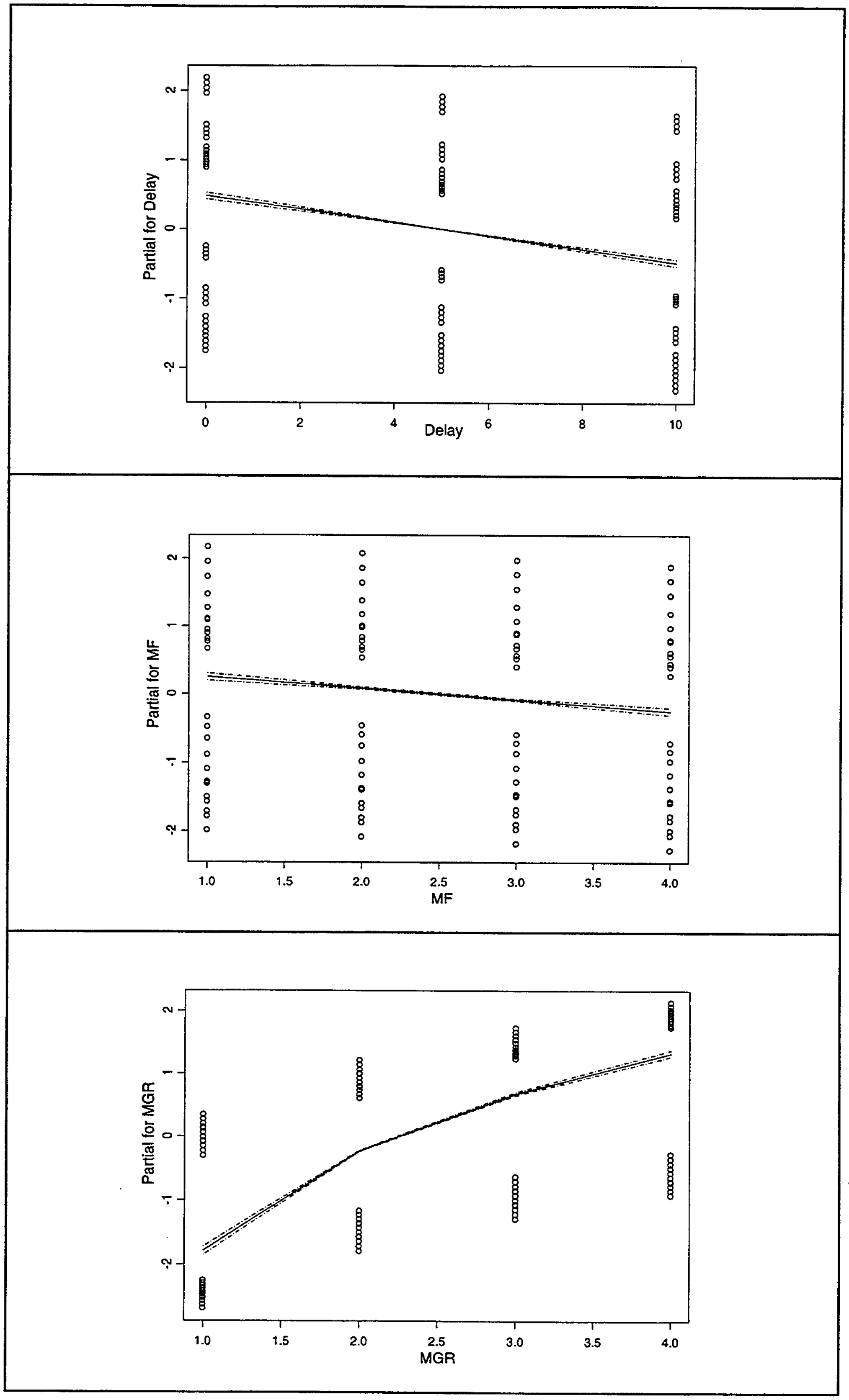

Figure 7. Partial Deviance Plot for each Explanatory Variable

The purpose of these plots is to identify any systematic behavior in the deviance residuals that could suggest a necessary transformation of one or more of the explanatory variables. The only plot that indicates a systematic behavior in the deviance residuals is the plot for the MGR variable. I was not able to identify a further transformation of the explanatory variables that could negate this effect. However, as stated above, the only intended use of logit-model is to summarize the data from the runs of the simulation model. Therefore, since the probabilities estimated with the logit-model correspond nicely to the values of the MOE estimated by the fraction of replications (see Figure 6), the logit-model is adequate to be used as a summary tool.

3. Results from the Logistic Regression Model

The first indication of the relative impact on the MOE from the three independent variables comes from the size of the estimated coefficients in the logit-model. Equation 4 (see page 33) shows that the most influential variable is clearly the SEAD mission generation rate (MGR). Even with the log-transformation, the estimated coefficient for the MGR is an order of magnitude larger than the coefficients for the Delay and MF variables. These latter two variables have estimated coefficients of approximately the same size.

Also, the equation shows that the MGR variable has an opposite influence on the logit of the MOE than the two other variables. The sign of the estimated coefficients show that the logit of the MOE increases with an increase in the MGR, but decreases with an increase in any of the two other variables. This is as expected, since an increase in the MGR means that more resources in the form of SEAD aircraft are allocated to the SEAD operation per day. Therefore, the SEAD operation must be expected to result in a higher probability of destroying all medium-range capability in the air defense system in the seven-day period.

The negative coefficients for the Delay and MF variables are also as expected. As described in the Chapter I (see page 3), inaccurate target data reduces the effectiveness of the SEAD operation. Both the Delay and MF variables negatively impact the accuracy level of the target data and should therefore be expected to have a negative coefficient in the logit-model.

To further investigate the relationship between the MOE and the three independent variables, it is necessary to take a look at how the three independent variables interact in respect to the MOE. To do this, the logit-model was used to estimate the MOE for forty-eight combinations of the independent variables. These combinations were the same as the runs from the simulation model (see page 25). The output from the logit-model will be discussed using a series of plots.

Figure 8 is a plot of the probability that all medium-range capability in the air defense system is destroyed at the end of the seven-day period (the MOE) versus the delay in the intelligence cycle (Delay). The figure has four groups of lines corresponding to the four possible values for the MGR variable. The upper group of four lines corresponds to a MGR = 4 and the lower group corresponds to a MGR = 1. Also, each group has four lines corresponding to the MF variable. Again, the upper line in each group corresponds to a MF = 1 and the lower line corresponds to a MF = 4.

Figure 8 shows that with an increase in the Delay, the MOE decreases. Also, the figure indicates that an increase in the MGR variable will influence the relationship between the Delay and the MOE. This can be seen from the difference in the slope of the lines in the four groups. The line slopes of the four groups also indicate that this relationship is not necessarily linear since the four groups develop differently. The figure indicates the four lines in each of the four groups are almost parallel over all three settings of the Delay variable. Thus, the relationship between the MF variable and probability is not influenced very much by the MGR.

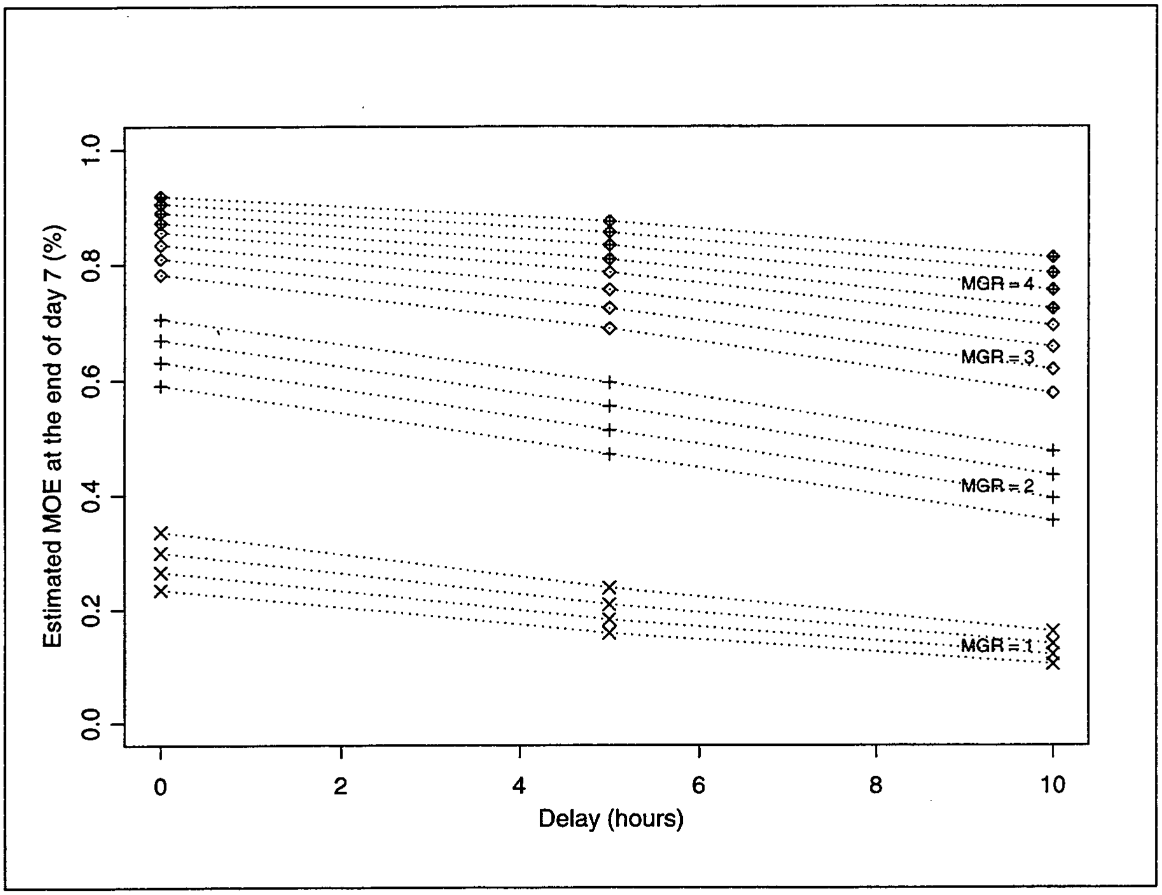

Figure 8. Plot of the Estimated MOE vs. Delay with data from the logit-model

To verify if these observations are statistically significant, it is necessary to calculate a confidence interval for the estimates shown in Figure 8. However, Ryan [Ref. 14: p. 275] states that "there is not at present (1997) a published approach for obtaining an exact confidence interval for π, so that the approximate confidence interval would have to be used." Here, π is the true probability that no medium-range capability remains in the air defense system at the end of the seven-day period (the MOE). I have used an approximate method described by D. Collett [Ref. 15: p. 89] to calculate the confidence intervals.

Figure 9 shows the upper group of four lines from Figure 8 (MGR = 4) plotted with the corresponding 90% confidence intervals. I used this group since it has the smallest distance between the lines. Note that Figure 9 uses a different scale for the estimated MOE than Figure 8. The figure shows that effect of the MF variable on the estimated values of the MOE are statistically significant since each line representing a particular setting of the MF is outside the neighboring confidence interval. Also, by comparing the confidence intervals on the same line at each setting for the Delay, it can be seen that the confidence intervals does not include the value for the MOE at an adjacent setting of the Delay. Hence, the effect of Delay variable is also statistically significant. The same situation holds for the three other groups not shown here.

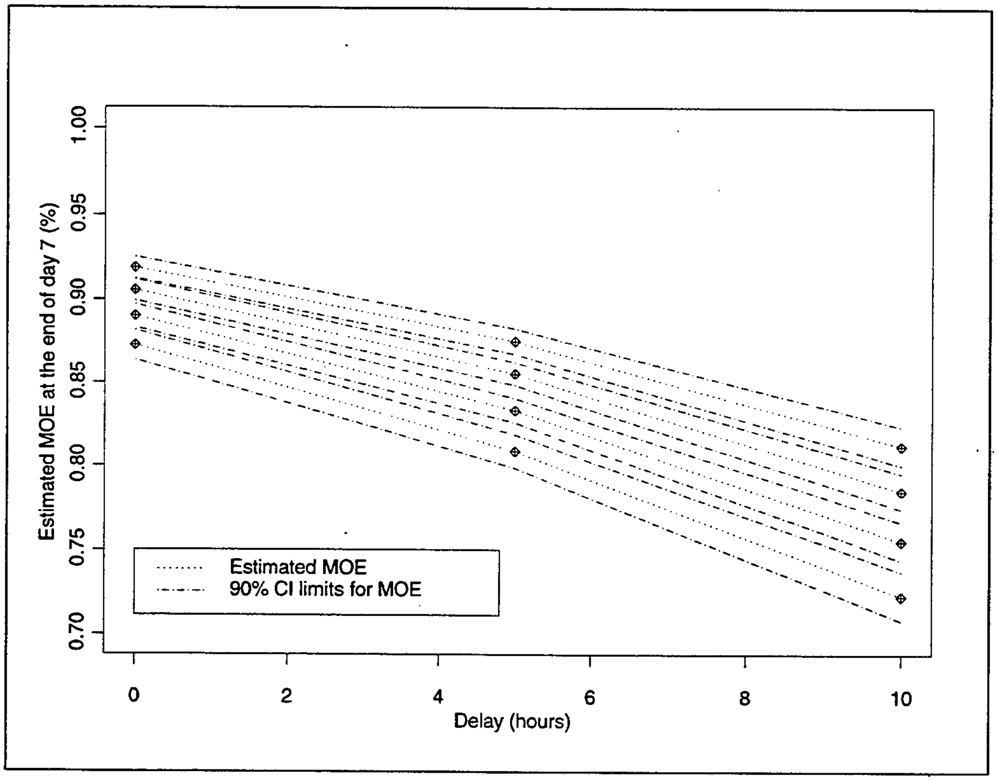

Figure 9. Plot of the estimated MOE vs. Delay with 90% Confidence Intervals (MGR = 4)

In summary, the Trellis bar-chart and the logit-model both indicate the same results. Both show that the most influential independent variable is the SEAD mission generation rate. Also, the two other independent variables have an effect since they both have coefficients in the logit model statistically different from zero.

This concludes the discussion of the results from the evaluation of the MOE. The next section investigates the distribution of the total number of killed SEAD aircraft during the operation period.

C. THE DISTRIBUTION OF KILLED SEAD AIRCRAFT

The purpose of this section is to investigate the effect of the three independent variables on the attrition of the SEAD aircraft. The section uses the same data-set as described in the section above with a total of forty-eight combinations of the independent variables. Recall that the combinations are

- Zero-, five- and ten-hour delay times in the intelligence cycle (Delay)
- One to four movements per air defense unit per day (MF)
- One to four SEAD missions generated per day (MGR)

The data used in this section are taken from the output list with the total number of killed SEAD aircraft. An example of the output list is given in Appendix B.

Figure 10 gives an overview of the average total number of killed SEAD aircraft in a Trellis bar-chart that shows all the forty-eight combinations of the independent variables. An explanation of how to read the Trellis graph is given on page 31. The horizontal bars in each panel describe the average total number of SEAD aircraft killed in the seven-day period and the line drawn at the end of each bar indicates a 90% *bias-corrected and accelerated* (BC_a) percentile interval [Ref. 12:p. 184]. A summary of the data is given in Appendix C.

The initial observation from Figure 10 is that the estimated average total number of killed SEAD aircraft exhibits no consistent effect from the movement frequency of the air defense units (MF). Also, the delay in the intelligence cycle (Delay) has, in general, a negligible effect and only a small one occurs when the SEAD mission generation rate (MGR) is high. The apparent effect in the upper row is not statistically significant since the percentile intervals for the adjacent bars overlap in several cases. The last independent variable, the SEAD mission generation rate, has an obvious significant effect since the length of the bars in the four rows are clearly different and the percentile intervals in general do not overlap for bars in the same position in different rows.

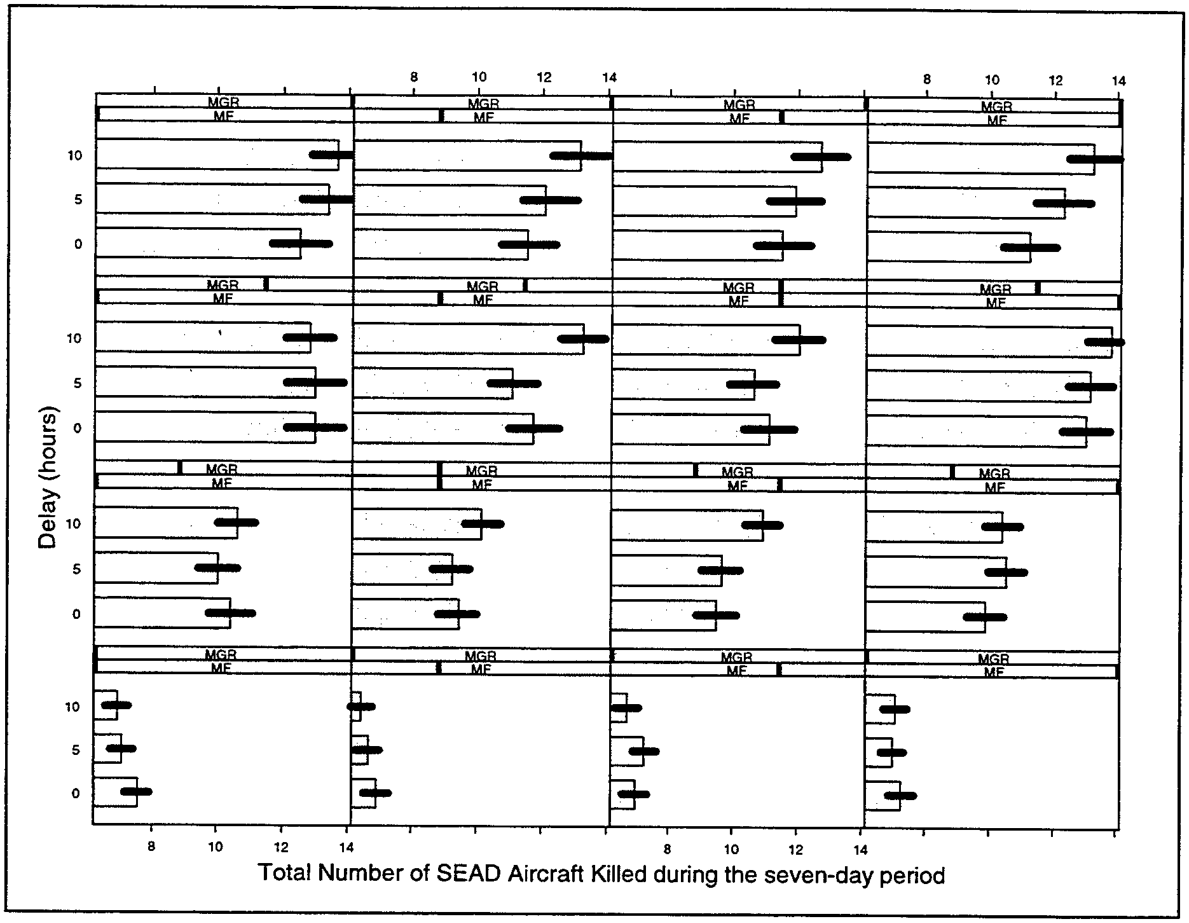

Figure 10. Trellis Bar-chart of the Total Number of Killed SEAD Aircraft during the seven-day period

To further investigate the significance level of the three independent variables, I used the *analysis of variance* (ANOVA) method as described by Larsen and Marx [Ref. 13:p. 494] to evaluate the impact on the total number of killed SEAD aircraft from each of the three independent variables. A necessary condition for using the ANOVA method to obtain a measure of statistical significance is that the samples compared in the test must be from distributions with constant and equal variance. Clearly, this condition is not met in this case. From Figure 10, it is obvious that the variance increases with the SEAD mission generation rate. Therefore, the use of the ANOVA method must be regarded as exploratory. The resulting p-values from the ANOVA for the three independent variables are shown in Table 6.

Parameter	p – value
Delay	0.088
MF	0.698
MGR	0.000

Table 6. The p-values from an ANOVA on the three independent variables

Table 6 confirms the observations from Figure 10. Using a smaller α-level to allow for the problem with the unequal variance, we see that the p-values confirm that the MF and Delay variables are not influential. However, even with the variance problem, the MGR variable is clearly statistical significant, as expected.

A possible explanation of the observed significance pattern can be found from the simulation model's use of a simplified scenario. The simulation model does not incorporate all of the tactics normally used by SEAD aircraft. All motion is carried out as a straight line between way-points. Also, the planning of the flight-route for a mission does not take possible threat sources into consideration as would be attempted in practice. In a real situation, the flight-route to and from the target area is planned to avoid known threats whenever possible. Hence, in this situation, one would expect that any inaccuracy in the threat data increase the chance of having a SEAD mission flying in the close vicinity of air defense units. However, with the simplifications in the simulation model, this effect is removed and consequently the effect of inaccurate target data is neutralized.

Before we go on to examine the units of the air defense system, let us briefly describe how the number of killed SEAD aircraft develops over the seven-day period. Figure 11 plots the average loss of SEAD aircraft per day for each day in the seven-day period. I have chosen to examine only the SEAD mission generation rate since this is the only statistically significant independent variable from the results discussed above. The figure has four lines with one corresponding to each setting of the MGR variable. The relationship between this figure and the total number of killed SEAD aircraft shown in Figure 10, is that the total number of killed SEAD aircraft for a particular variable combination is the area under the corresponding curve in Figure 11.

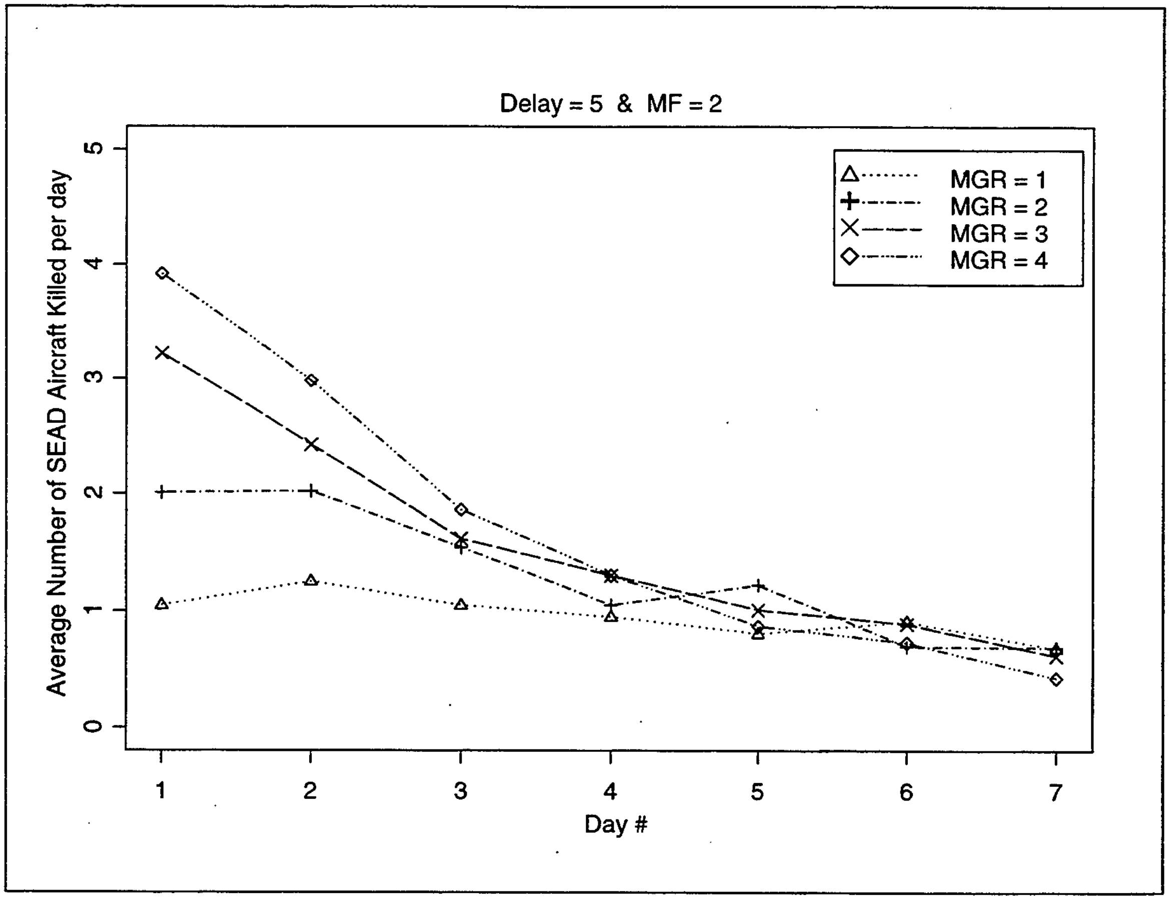

Figure 11. Plot of the Average Number of SEAD Aircraft killed per day over the seven-day operation period

Figure 11 shows that the impact of the MGR variable is obvious in the beginning, but decreases toward the later stage of the operation period. A possible reason is, of course, that more air defense units have been destroyed by the later part of the period, and therefore, the SEAD missions confront a less capable opponent in the later stages of the operation.

To summarize the results from this section, the average total number of killed SEAD aircraft does not show an important impact from either an increase in the delay time in the intelligence cycle or an increase in the movement frequency of the air defense units. Hence, the only independent variable with an obvious and statistically significant impact on the average total number of killed SEAD aircraft, is the SEAD mission generation rate (MGR). Finally, the average number of SEAD units lost per day is, as expected, dependent on the total number of SEAD aircraft sent toward the air defense system. However, this effect diminishes in the later part of the period due to a reduction in the number of operational air defense units.

The next section describes the data generated for the average total number of killed air defense units during the seven-day period.

D. THE ATTRITION RATE OF THE DIFFERENT AIR DEFENSE UNITS

The purpose of this section is to investigate the effect of the three independent variables on the attrition of the units in the air defense system. The section uses the same data-set as described above with a total of forty-eight combinations of the independent variables. The combinations are described on page 41. However, the data used in this section are taken from the output lists listing the total number of killed air defense units in each category. An example of the output list is given in Appendix B.

To reiterate the categories, these are

- Four fire-distribution centers (FDC)
- Four air surveillance radars
- Nine medium-range surface-to-air missile systems (MSAM)
- Eighteen short-range surface-to-air weapon systems

Let us start the description with a look at the generated data for the total number of killed fire-distribution centers at the end of the seven-day period.

1. The Average Total Number of Killed Fire-Distribution Centers

Figure 12 shows the average total number of killed FDC at the end of the seven-day period for all forty-eight combinations of the independent variables plotted in a Trellis bar-chart. The average is based on the three hundred replications for each combination of the independent variables. An explanation of how to read the Trellis graph is given on page 31.

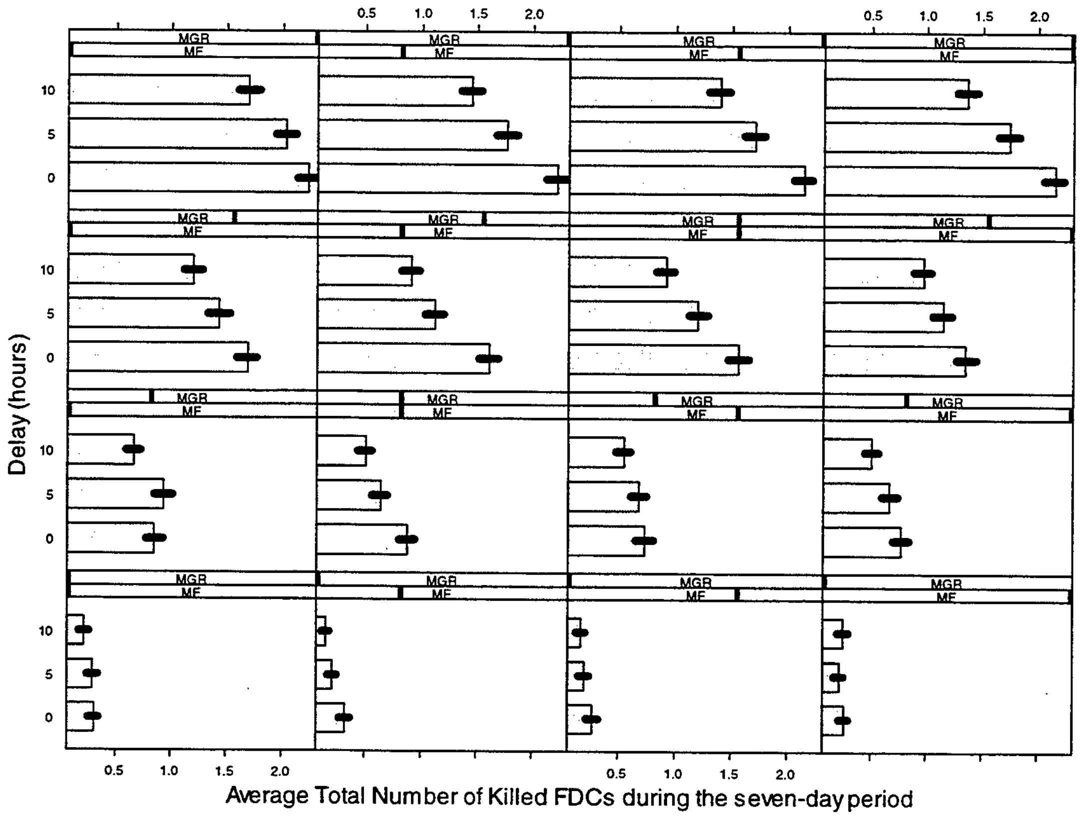

Figure 12. Trellis bar-chart of the Average Total Number of Killed Fire Distribution Centers at the end of the seven-day period

The initial observation from Figure 12 is that, again, the most influential variable is the SEAD mission generation rate since the average value clearly increases with each row. This is a logical observation since one expects to see more air defense units killed if more SEAD missions are used.

Also, the Delay variable has an effect since the difference between the bars in each panel is often larger than the corresponding 90% percentile intervals. However, the effect is dependent on the setting for the MGR variable. The two lower rows (MGR = 1 and MGR = 2) show a situation where the effect of the Delay is limited while the upper two rows (MGR = 3 and MGR = 4) show some statistically significant effects. This effect may come as a surprise, but can be explained from the size of the average number of killed FDCs. As can be seen, for the two lower rows, the average number of killed FDCs is very small. The bars have an approximately equal length since there are not enough SEAD missions to successfully attack many FDCs as assigned targets. Hence, the effect of the Delay is low. When the number of SEAD missions has reached a sufficient level, the impact of the Delay increases, as expected.

A third observation from Figure 12 is related to the movement frequency (MF) variable. Again, the two lower rows show no statistically significant effect of the variable. However, the two upper rows indicate a small effect since the length of the bars in the panels in general decreases when reading across the columns from left to right.

2. The Average Total Number of Killed Air Surveillance Radars

The average total number of killed air surveillance radars at the end of the seven-day period is plotted as a Trellis bar-chart in Figure 13. In general, the setup for the figure is the same as that of Figure 12, but this time with the average total number of killed radars on the x-axis in each panel.

As expected, the most influential variable is the SEAD mission generation rate. The average total number of killed radars increases with an increasing MRG. However, the relationship is not linear since the two upper rows with different settings for the MGR are almost identical and different from the situation in the two lower rows. The reason for the non-linearity is that the upper rows show a situation where the average number of killed radars is very close to total number of radars (four). In other words, a MGR = 3 is sufficient to kill almost all radars, and consequently, an increase to a MGR = 4 cannot significantly improve the outcome.

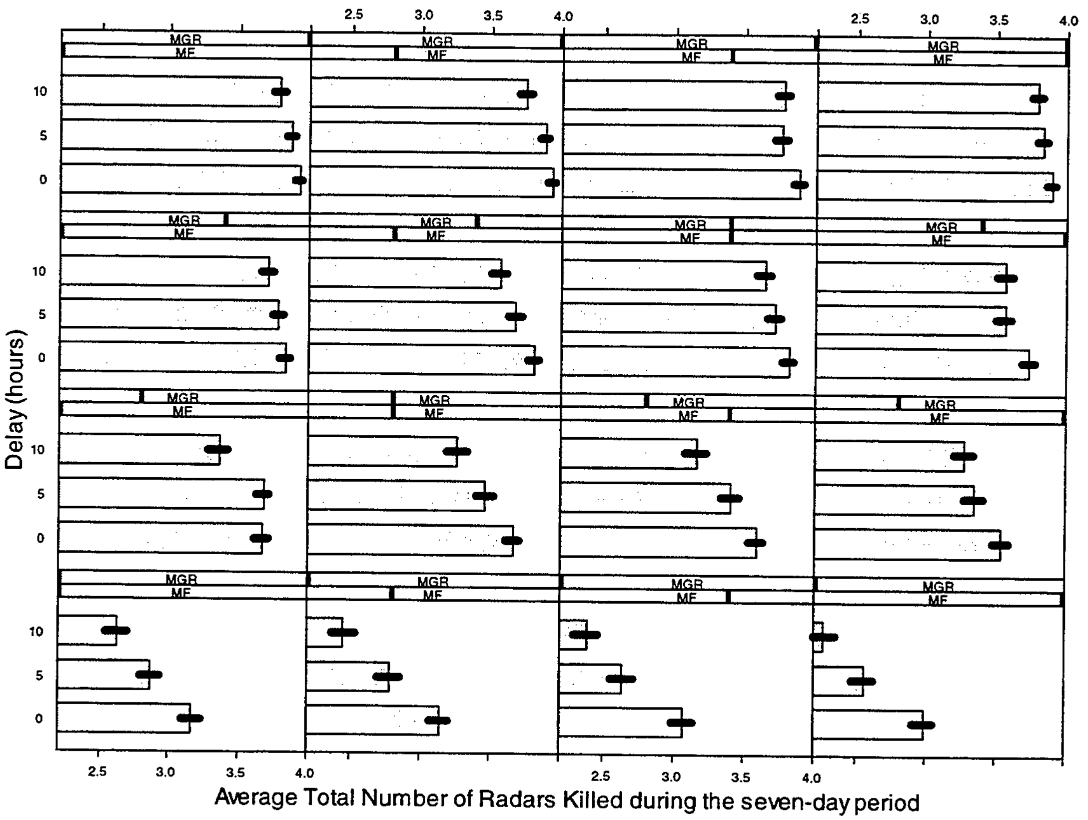

Figure 13. Trellis bar-chart of the Average Total Number of Air Surveillance Radars killed during the seven-day period

Figure 13 also indicates that the Delay variable has an effect on the average total number of killed radars. Again, the effect of the Delay variable is dependent on the setting of the MGR variable since the effect of the Delay variable is much more apparent in the two lower rows than in the two upper. The reason is that, as described for the MGR variable, the average total number of killed radars is very close to the total number of radars.

The effect of the MF variable is negligible. This is expected since the radars are mainly targeted by Wild Weasel aircraft. As stated in Chapter I, the Wild Weasel has a very large detection range that tends to neutralize any effect of the movement by the air surveillance radars. Also, the simulation model uses a limited air defense operation area (100 x 100 km). As a result, the magnitude of the movement is restricted. This will further increase the neutralizing effect from the Wild Weasel aircraft since the aircraft before take-off already have a good indication of where the air surveillance radars can be located.

3. The Average Total Number of Killed Medium-Range SAM Systems

The last category of air defense units specifically discussed is that of the medium-range SAM systems (MSAM). A similar depiction to the Trellis bar-charts for the FDCs and the radars is given in Figure 14. Here, the x-axis in each panel is the average total number of killed MSAMs during the seven-day period.

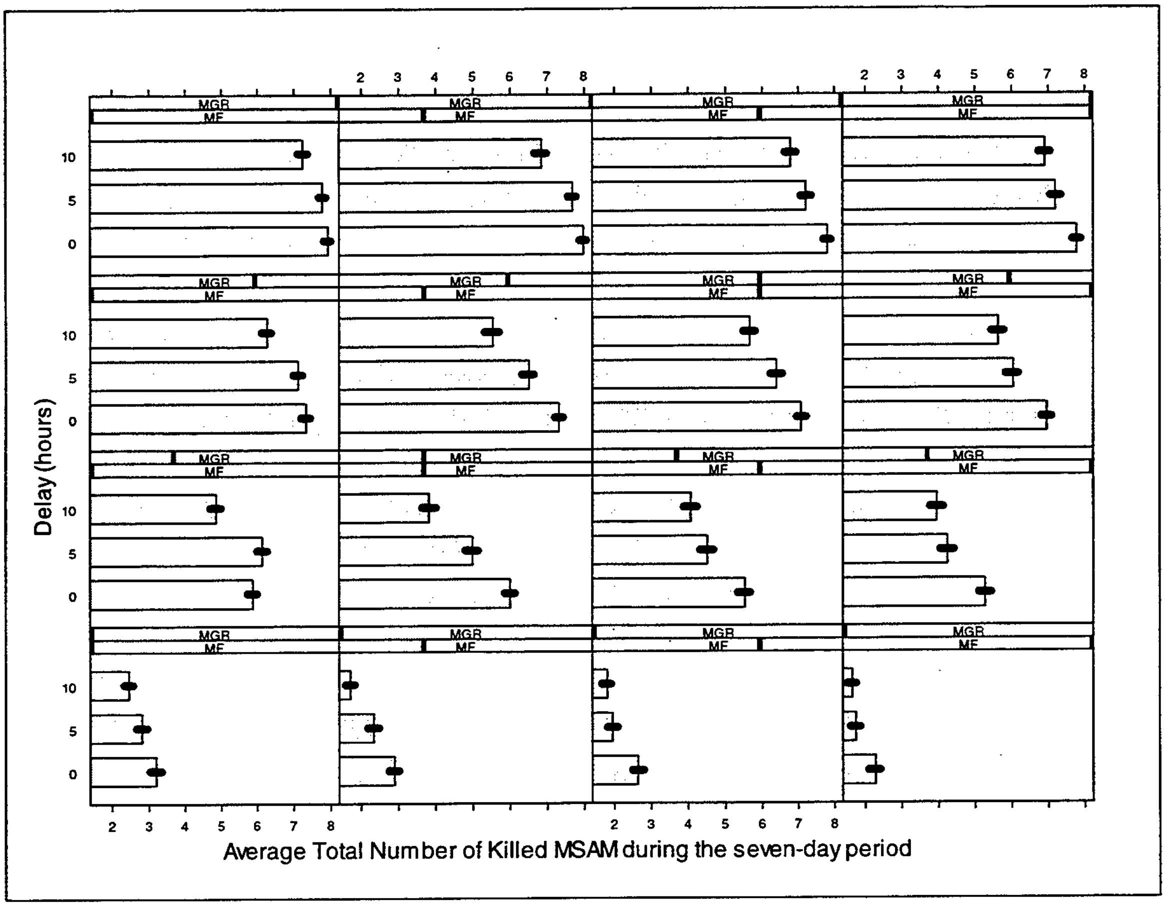

Figure 14. Trellis bar-chart of the Average Total Number of Killed Medium-Range Surface-to-Air Missile Systems (MSAM) during the seven-day period

Again, the MGR is the most influential variable and the average total number of killed MSAMs increases with an increase in the MGR. The reason for this relationship is the same as described for the FDCs. Also, the difference in lengths of the three horizontal bars in each panel indicates that the Delay variable has an effect. In other words, as expected, the average total number of killed MSAMs decreases with an increase in the Delay variable. Finally, it is not possible from the figure to establish any consistent influence from the MF variable.

4. Significance of Observations

To further explore the level of statistical significance of the results, I have again used the *analysis of variance* (ANOVA) method as described by Larsen and Marx [Ref. 13:p. 494] on each of the three categories of air defense units. The ANOVA used the same data-sets as depicted in the Trellis bar-charts in the previous sections. Also, I included the data generated for the short-range SAM systems. Before we review the results from the ANOVA, it is necessary to briefly examine the variability in each data-set. This is necessary because of the constant variance assumption of the ANOVA. Looking back at the Trellis graphs, the variability in each data-set can be estimated from the percentile intervals drawn at the end of each horizontal bar. Each of the three graphs indicates a different pattern. The bar-chart for the FDCs (Figure 12) show a pattern where the variability increases with an increase in the SEAD mission generation rate. In other words, the percentile intervals are longer in the upper rows. The bar-chart for the air surveillance radars shows a different pattern. Here, the variability is smaller in the upper rows. Finally, the bar-chart from the MSAMs does not indicate an obvious variability pattern. To conclude, the only unit category that indicates an approximately constant variance is the MSAMs. Consequently, the output from the ANOVA must be viewed as an exploratory exercise. The resulting p-values from the ANOVA are shown in Table 7.

	Delay	**MF**	**MGR**
FDC	0.0	0.02	0.0
Radar	0.0	0.03	0.0
MSAM	0.0	0.0	0.0
SRSAM	0.3	0.0	0.0

Table 7. Significance Level for the Independent Variables in form of p-values from ANOVA

The p-values in Table 7 must be regarded as an indication only, since the three Trellis bar-charts described above demonstrated that the constant variance condition of the ANOVA are not met. With this in mind, the table shows that for all categories except short-range weapon systems, the independent variables have a p-value indicating an effect. The relatively large p-value for the Delay in the short-range weapon systems is expected since these are not attacked by SEAD missions as assigned targets and therefore are not impacted by the delay in the intelligence cycle.

The final topic in this section is related to the MOE's lack of sensitivity to a change in the MF variable as described on page 43. Throughout this chapter, it has become obvious that the impact of the MF variable is probably negligible over the range considered. The reason for this can be explained from Figure 15, which shows a typical example of how the number of operational FDCs, radars and MSAMs decrease over the seven-day period. Figure 15 has three lines for each of the three categories of air defense units representing a zero-, five- and ten-hour delay in the intelligence cycle. The figure shows the setting for the Delay only for one category, but the pattern is the same for the two other categories. The settings for the two other variables are MGR = 4 and MF = 4.

Figure 15 shows that the critical unit category in the air defense system is the air surveillance radars. The reason for this can be found in the simulation model's target priority scheme (see page 19). The simulation model always targets air surveillance radars with top priority. In general, these radars are attacked using Wild Weasel aircraft. The Wild Weasel, with its large detection range, neutralizes the effect of the movement of the radar. Thus, the SEAD operation becomes less sensitive to the MF variable and the medium-range capability of the air defense system becomes dependent on the number of operational radars.

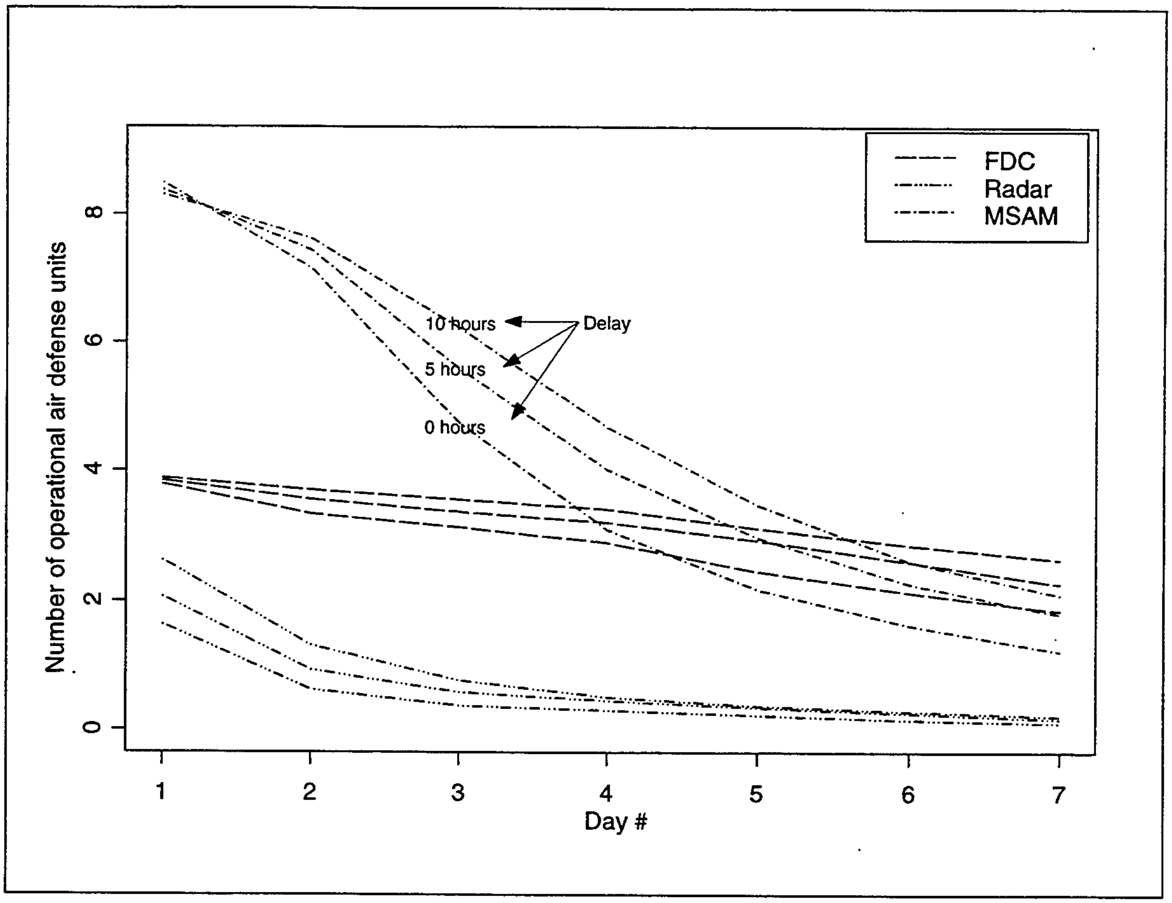

Figure 15. Number of Operational Air Defense Units during the seven-day period

In summary, the output from the ANOVA suggests that all three independent variables have a statistically significant impact on the average total number of killed air defense units in each category. Of the three independent variables, the SEAD mission generation rate is clearly the most influential, as expected. Also, the delay time in the intelligence cycle has an observable effect, but this effect is in most cases dependent on the setting for the MGR variable. The third variable, the movement frequency of the air defense units, has a statistically significant p-value from the ANOVA. However, the observations from the figures were only able to establish a small operational influence, for reasons explained above.

V. SUMMARY AND CONCLUSIONS

The overall purpose of this thesis was to investigate the effectiveness of a SEAD operation against a new-generation surface-based air defense system. In particular, the thesis addressed one primary question:

- **To what degree does a delay in the intelligence cycle impact the effectiveness of a SEAD operation against a new-generation surface-based air defense system?**

In addition, the thesis investigated two related questions:

- **To what degree does the effect of the delay change if the air defense units change positions more frequently?**

- **How does a change in the number of SEAD missions sent to attack the air defense system per day influence the SEAD operation's effectiveness, given the delay in the intelligence cycle?**

To address these questions, the thesis used the output from a low-resolution simulation model constructed with a simplified, but representative scenario for a SEAD operation against a new-generation air defense system over a seven-day period. The output data from the simulation model was in the form of forty-eight runs with different settings of the three independent variables. Each run had three hundred replications.

A Logistic Regression model is used to summarize a Measure of Effectiveness defined as *the probability that the enemy air defense system has lost its medium-range capability by the end of day seven.* The relationships from this model were further verified through investigating the attrition rates of the units of the air defense system and the attrition rate for the SEAD aircraft.

The simple experimental design, the very limited number of simulation runs, and the many assumptions and simplifications in the simulation model mean that precise numerical answers cannot be considered to be accurate. However, the analysis could be used to identify general trends.

Results of the model analysis showed that the effectiveness of a SEAD operation *is* influenced by a delay in the intelligence cycle, but not to the anticipated degree. The impact of the delay is reduced because a new-generation air defense system still depends on the use of air surveillance radars. Hence, the SEAD forces can still rely on the weapon systems that have ensured a dominance over air defense systems over the last two decades. Using the Logistic Regression model, the attrition rate for the SEAD aircraft, and the attrition rates for the different categories of air defense units, it is deduced that the most influential variable for the success of a SEAD operation is the number of SEAD missions per day. The impact of this variable has been found to be of an order of magnitude more influential than the two other variables. The delay time in the intelligence cycle and the movement frequency of the air defense units were both statistically significant, but contributed to a lesser degree.

The analysis concludes that there is a statistically significant reduction in the effectiveness of a SEAD operation from an increased delay in the intelligence cycle. The question is, then, if this reduction is *operationally* significant. The answer to this question is dependent on the air force conducting the SEAD operation. A large and sophisticated air force will probably not allow the delay to become too large. However, for a small air force, it is not unheard of to encounter delays in the range of more than ten hours. In this case, the impact of the delay becomes operationally important.

This thesis suggests that a SEAD operation against a new-generation air defense system might face a much more capable opponent. However, new-generation air defense systems still rely on the radar as the only source for air surveillance, allowing the SEAD operation to keep on using the traditionally very effective SEAD assets such as Wild Weasel aircraft equipped with anti-radiation missiles. To overcome this weakness, it must be expected that the new-generation air defense systems will be equipped with passive surveillance sensors, thereby negating the effect of Wild Weasel aircraft. Arntzen

[Ref. 16:p 52] states that passive sensors with the required capability are currently available or will be in the near future. The introduction of passive sensors must be expected to further increase a SEAD operation's sensitivity to a delay in the intelligence cycle.

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APPENDIX A. THE NASAMS SURFACE-TO-AIR MISSILE SYSTEM

This appendix contains a description of the Norwegian Advanced Surface-to-Air Missile System (NASAMS). The source of information for the appendix is a set of briefing notes from a standard unclassified visitor brief given at the Air Defense Battalion at Bardufoss Air Station in Norway in 1998.

1. HISTORY

The Royal Norwegian Air Force (RNoAF) started the development of a new medium-range air defense system in the early 1980s. The system used the existing US Hawk air defense system, but incorporated a new three-dimensional air surveillance radar and a new fire-control system. This system was called Norwegian Adapted Hawk (NOAH) and reached operational status in the mid 1980s. However, the Hawk system has inherent limitations since it uses a guidance system with target illumination radars. Consequently, the RNoAF wanted to upgrade the missile part of the NOAH system. Development of an upgraded system started in the early 1990s. The new development concentrated on the introduction of new surface-to-air missile and an upgrade of the computer and communication systems. The new missile is a ground-launched version of the US Advanced Medium-range Air-to-Air Missile (AMRAAM). The resulting air defense system is named the Norwegian Advanced Surface-to-Air System (NASAMS) and was declared operational after a large live-firing test carried out in Texas in August 1998. The RNoAF mainly uses NASAMS for air defense of their air stations, but a version of NASAMS is currently being developed for the Norwegian Army as an air defense system for its divisions.

2. COMPONENTS OF NASAMS

NASAMS is a modular system and can be set up according to the need of a particular situation. A typical setup includes four air surveillance radars, four fire-distribution centers, six to nine medium-range surface-to-air missile (SAM) launchers and a mix of short-range surface-to-air weapons. The radars, fire-distribution centers and the medium-range SAMs comprise the medium-range capability of the system. The rest of this section gives an overview of the different component types.

a. The Acquisition Radar and Control System

The Acquisition Radar and Control System (ARCS) is a combination of one low altitude surveillance radar (LASR) and one fire-distribution center (FDC). The LASR is hooked up to the FDC by cables. Hence, it must be positioned no more than fifty meters from the FDC. Development is, however, underway to increase this distance to more than a kilometer through the use of optical fiber technology. The LASR is a three-dimensional phased array radar with a maximum range of 75 km. The radar can track more than 60 targets simultaneously and has IFF built in. The FDC receives track data from the LASR and has a dual role as a fire-control system and a command and control installation. The main responsibilities are to identify the incoming tracks, to evaluate what threat the tracks constitute, and to order the launch of surface-to-air missiles to attack the incoming threat. All these functions can be automated. Both the LASR and the FDC are mobile, but have to be stationary to operate.

All ARCS are linked up in a network. This means that only one ARCS is sufficient to provide target data to all medium-range SAM launchers. The normal operation mode is however to have at least two LASRs emitting at the same time to ensure sufficient radar coverage. Also, the network enables the system to use jam strobe triangulation to track enemy jammer aircraft.

b. The Surface-to-Air Missile

The surface-to-air missile is a ground-launched version of the US AMRAAM missile. Each missile launcher has six AMRAAM missiles ready for launch. Also, the missile launchers are mobile, but need to be stationary when launching missiles. Each launcher can be placed up to 25 km from the nearest FDC depending only on possible communications limitations.

The AMRAAM missile has an onboard active radar seeker. Therefore, the only needed communication between the launcher and the FDC is limited to providing the missile with target data before launch. The AMRAAM missiles have a build-in logic enabling several missiles to engage a group of targets simultaneously. The ground-launched AMRAAM has a maximum engagement range of approximately 15 km.

c. Short-range Weapons

To complement the medium-range capability, the NASAMS uses two different short-range weapon systems. The first is the Swedish Rb-70 missile system. This system has a range of approximately 7 km and uses a laser beamriding guidance system. The second short-range system is the Swedish L-70 anti-aircraft artillery system. The L-70 system comprises a number of forty millimeter guns controlled from a centralized fire-control system. The effective engagement range for the L-70 is limited to approximately 4 kilometers.

In summary, the modular structure of the NASAMS results in a very flexible air defense system with a very high firepower. The main strength of the system is the network structure of the surveillance and fire-control units and the use of a missile without a target illumination radar. The RNoAF is currently considering updating the NASAMS with infrared search and track (IRST) devices and other passive sensors. If these are incorporated, the NASAMS will be able to operate totally without radar emission and as such will be a formidable opponent for an enemy SEAD operation.

APPENDIX B. EXAMPLE OF OUTPUT FILE FROM SIMULATION MODEL

This appendix contains an example of the output file from the simulation model. The output example is of a run with 10 replications. The setting of the independent variables in this run is given in the first line of the output file. The abbreviations are 1) Mission Generation Rate (MGR) in number of SEAD missions per day, 2) the delay in the SEAD intelligence cycle (delay) in minutes, and 3) the movement frequency of the air defense units (MF) in number of movements per unit per day.

The first five lists should be self-explanatory from the heading given above each list. However, the last list termed "Non-operational IADS" may need an explanation. This list contains a binary value given as either zero or one. The value indicates if the air defense system retains medium-range capability or not. A value one means that the air defense system retains medium-range capability, and, conversely, the value zero means that all medium-range capability are destroyed. The value is decided by going through the lists: "Number Radar alive," "Number FDC alive," and "Number MSAM alive." If any of these lists, at a specific day and at a specific replication, has a value of zero, the "Non-operational IADS" list will also have the value zero for the corresponding entry. Otherwise, the value is one. The "Non-operational IADS" list is used to calculate the Measure of Effectiveness as described in Chapter III.

Parameter Setup # 1   MGR = 1.0   Delay = 0.0   MF = 1.0

Number Radar alive

Run #	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	4	4	3	2	2	2	1	1
2	4	4	4	3	2	1	1	1
3	4	4	4	4	4	3	2	2
4	4	4	2	1	1	1	1	1
5	4	3	1	1	1	1	1	1
6	4	3	2	2	2	2	2	2
7	4	4	4	4	4	4	2	2
8	4	2	2	2	2	2	2	1
9	4	3	2	0	0	0	0	0
10	4	4	2	2	1	1	1	1

Number FDC alive

Run #	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	4	4	3	3	3	3	2	2
2	4	3	3	3	3	3	3	3
3	4	4	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4
5	4	4	4	4	4	4	4	4
6	4	4	4	4	4	4	4	4
7	4	4	4	4	4	4	4	4
8	4	4	4	4	4	4	4	4
9	4	4	4	4	3	3	3	3
10	4	4	4	4	4	4	4	4

Number MSAM alive

Run #	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	9	9	9	9	7	7	7	6
2	9	9	9	9	9	9	8	6
3	9	9	9	7	7	7	7	6
4	9	9	9	9	8	5	5	4
5	9	9	9	8	8	7	7	5
6	9	9	9	7	7	6	5	4
7	9	8	8	8	8	8	8	7
8	9	9	9	8	7	7	7	7
9	9	9	9	9	9	8	6	6
10	9	9	9	9	9	8	6	6

Number SRSAM alive

Run #	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	18	18	18	18	18	18	18	18
2	18	18	18	18	18	18	18	18
3	18	18	18	18	18	18	18	18
4	18	17	17	17	17	17	17	17
5	18	18	18	18	18	18	18	18
6	18	18	18	18	18	18	18	18
7	18	18	18	18	18	18	18	18
8	18	18	18	18	18	18	18	18
9	18	18	18	18	18	18	18	18
10	18	18	18	18	18	18	18	18

Total number of A/C lost per day

Run #	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	0	0	2	3	1	0	0	2
2	0	2	2	2	0	0	0	2
3	0	3	2	0	2	0	2	3
4	0	1	2	0	0	0	0	2
5	0	2	1	4	0	1	3	0
6	0	2	1	0	0	0	0	2
7	0	0	2	0	2	2	1	0
8	0	0	0	0	4	1	0	0
9	0	2	0	0	0	0	0	0
10	0	0	3	0	2	0	0	0

Non-operational IADS

Run #	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1
9	1	1	1	0	0	0	0	0
10	1	1	1	1	1	1	1	1

Run time is 30 seconds

APPENDIX C. SUMMARY OF GENERATED DATA

This appendix contains several summaries of the generated data for the thesis. The summaries are in the form of six tables. These are

- Table 1 - the estimated probability that all medium-range capability in the air defense system is destroyed at the end of day 7. This is the MOE described in Chapter II.
- Table 2 - the sample mean and standard error of the total number of SEAD aircraft killed during the seven-day period.
- Table 3 - the sample mean and standard error of the total number of Fire Distribution Centers killed during the seven-day period.
- Table 4 - the sample mean and standard error of the total number of Air Surveillance Radars killed during the seven-day period.
- Table 5 - the sample mean and standard error of the total number of medium-range surface-to-air missile launchers (MSAM) killed during the seven-day period.
- Table 6 - the sample mean and standard error of the total number of short-range weapon systems (SRSAM) killed during the seven-day period.

All tables are based on runs with n = 300 replications. The sample mean, standard error (SE) and percentage intervals (PI) are obtained by bootstrapping the generated data with a number of replications in the bootstrap, B= 1000.

All tables have forty eight rows, one row for each combination of the independent variables. The value of the variables are given in the three first columns of each table. The abbreviations mean:

- Delay - the delay in the SEAD intelligence cycle (in hours)
- MF - The movement frequency of the air defense units (in number of movements per unit per day)
- MGR - The SEAD mission generation rate (in number of SEAD missions per day)

Table 1. Summary Statistics for MOE at the End of Day Seven (n=300)

	Parameters							90 % Percentage Interval		
Combination #	Delay	MF	MGR		Mean	SE		Lower limit	Upper limit	PI length
1	0	1	1		0.33	0.03		0.29	0.38	0.09
2	5	1	1		0.23	0.02		0.19	0.26	0.08
3	10	1	1		0.16	0.02		0.13	0.20	0.07
4	0	2	1		0.33	0.03		0.28	0.37	0.08
5	5	2	1		0.21	0.02		0.17	0.25	0.08
6	10	2	1		0.11	0.02		0.07	0.13	0.06
7	0	3	1		0.32	0.03		0.28	0.36	0.09
8	5	3	1		0.15	0.02		0.11	0.18	0.07
9	10	3	1		0.12	0.02		0.09	0.15	0.06
10	0	4	1		0.26	0.03		0.22	0.30	0.08
11	5	4	1		0.14	0.02		0.10	0.17	0.07
12	10	4	1		0.09	0.02		0.06	0.12	0.05
13	0	1	2		0.70	0.03		0.65	0.74	0.09
14	5	1	2		0.69	0.03		0.64	0.73	0.09
15	10	1	2		0.49	0.03		0.43	0.53	0.10
16	0	2	2		0.68	0.03		0.63	0.72	0.09
17	5	2	2		0.53	0.03		0.48	0.58	0.09
18	10	2	2		0.40	0.03		0.35	0.45	0.10
19	0	3	2		0.61	0.03		0.56	0.65	0.09
20	5	3	2		0.50	0.03		0.44	0.54	0.10
21	10	3	2		0.38	0.03		0.33	0.42	0.09
22	0	4	2		0.57	0.03		0.52	0.62	0.09
23	5	4	2		0.46	0.05		0.41	0.50	0.10
24	10	4	2		0.44	0.05		0.39	0.48	0.09
25	0	1	3		0.84	0.02		0.80	0.87	0.07
26	5	1	3		0.78	0.02		0.74	0.82	0.08
27	10	1	3		0.71	0.03		0.67	0.75	0.09
28	0	2	3		0.81	0.02		0.77	0.84	0.08
29	5	2	3		0.68	0.03		0.64	0.73	0.09
30	10	2	3		0.60	0.03		0.55	0.64	0.09
31	0	3	3		0.82	0.02		0.77	0.84	0.07
32	5	3	3		0.73	0.03		0.67	0.76	0.09
33	10	3	3		0.66	0.03		0.61	0.70	0.09
34	0	4	3		0.75	0.03		0.70	0.79	0.08
35	5	4	3		0.59	0.03		0.53	0.63	0.10
36	10	4	3		0.60	0.03		0.55	0.65	0.10
37	0	1	4		0.94	0.01		0.91	0.96	0.05
38	5	1	4		0.87	0.02		0.84	0.90	0.06
39	10	1	4		0.80	0.02		0.76	0.84	0.08
40	0	2	4		0.94	0.01		0.91	0.96	0.05
41	5	2	4		0.88	0.02		0.85	0.91	0.06
42	10	2	4		0.77	0.02		0.72	0.80	0.08
43	0	3	4		0.89	0.02		0.85	0.91	0.06
44	5	3	4		0.76	0.02		0.72	0.80	0.08
45	10	3	4		0.77	0.02		0.73	0.81	0.08
46	0	4	4		0.90	0.02		0.86	0.92	0.06
47	5	4	4		0.84	0.02		0.80	0.87	0.07
48	10	4	4		0.79	0.02		0.75	0.83	0.07

Table 2. Summary Statistics of Total Number of Killed SEAD Aircraft (n=300)

	Parameters							90 % Percentage Interval		
Combination #	Delay	MF	MGR		Mean	SE		Lower limit	Upper limit	PI length
1	0	1	1		7.54	0.23		7.15	7.90	0.75
2	5	1	1		7.04	0.21		6.71	7.41	0.71
3	10	1	1		6.89	0.20		6.54	7.21	0.67
4	0	2	1		6.93	0.23		6.58	7.34	0.76
5	5	2	1		6.70	0.22		6.32	7.05	0.73
6	10	2	1		6.47	0.20		6.16	6.81	0.65
7	0	3	1		6.95	0.23		6.55	7.31	0.76
8	5	3	1		7.23	0.23		6.86	7.58	0.72
9	10	3	1		6.68	0.22		6.33	7.08	0.74
10	0	4	1		7.28	0.23		6.93	7.69	0.76
11	5	4	1		7.02	0.21		6.70	7.38	0.68
12	10	4	1		7.10	0.22		6.77	7.48	0.71
13	0	1	2		10.43	0.40		9.77	11.08	1.31
14	5	1	2		10.04	0.37		9.42	10.62	1.19
15	10	1	2		10.63	0.35		10.02	11.16	1.14
16	0	2	2		9.45	0.36		8.81	10.00	1.19
17	5	2	2		9.25	0.35		8.67	9.79	1.11
18	10	2	2		10.14	0.33		9.61	10.68	1.07
19	0	3	2		9.50	0.38		8.89	10.14	1.25
20	5	3	2		9.67	0.36		9.07	10.23	1.16
21	10	3	2		10.93	0.33		10.37	11.45	1.08
22	0	4	2		9.88	0.35		9.34	10.47	1.13
23	5	4	2		10.52	0.35		9.96	11.11	1.14
24	10	4	2		10.40	0.33		9.90	11.01	1.11
25	0	1	3		12.98	0.52		12.18	13.84	1.65
26	5	1	3		12.98	0.52		12.18	13.84	1.65
27	10	1	3		12.82	0.44		12.14	13.57	1.42
28	0	2	3		11.73	0.45		11.03	12.49	1.46
29	5	2	3		11.08	0.43		10.41	11.83	1.43
30	10	2	3		13.24	0.40		12.59	13.90	1.31
31	0	3	3		11.13	0.47		10.34	11.86	1.51
32	5	3	3		10.65	0.43		9.90	11.37	1.46
33	10	3	3		12.06	0.45		11.28	12.76	1.48
34	0	4	3		13.03	0.47		12.22	13.80	1.58
35	5	4	3		13.17	0.44		12.45	13.88	1.43
36	10	4	3		13.83	0.48		13.05	14.61	1.57
37	0	1	4		12.49	0.53		11.62	13.35	1.73
38	5	1	4		13.37	0.50		12.57	14.25	1.67
39	10	1	4		13.65	0.50		12.87	14.51	1.65
40	0	2	4		11.53	0.53		10.67	12.39	1.72
41	5	2	4		12.08	0.49		11.36	13.03	1.67
42	10	2	4		13.13	0.53		12.33	14.02	1.69
43	0	3	4		11.52	0.51		10.73	12.43	1.70
44	5	3	4		11.92	0.52		11.10	12.73	1.63
45	10	3	4		12.71	0.50		11.87	13.49	1.62
46	0	4	4		11.23	0.51		10.41	12.08	1.68
47	5	4	4		12.31	0.55		11.42	13.17	1.75
48	10	4	4		13.24	0.48		12.45	14.05	1.60

Table 3. Summary Statistics of the Total Number of FDCs Killed (n = 300)

	Parameters							90 % Percentage Interval		
Combination #	Delay	MF	MGR		Mean	SE		Lower limit	Upper limit	PI length
1	0	1	1		0.31	0.03		0.26	0.35	0.09
2	5	1	1		0.29	0.03		0.25	0.34	0.09
3	10	1	1		0.22	0.03		0.17	0.26	0.09
4	0	2	1		0.32	0.03		0.27	0.37	0.10
5	5	2	1		0.21	0.02		0.17	0.24	0.08
6	10	2	1		0.15	0.02		0.11	0.18	0.07
7	0	3	1		0.28	0.03		0.23	0.32	0.09
8	5	3	1		0.21	0.02		0.16	0.25	0.08
9	10	3	1		0.18	0.02		0.14	0.21	0.07
10	0	4	1		0.26	0.03		0.21	0.30	0.08
11	5	4	1		0.21	0.03		0.17	0.25	0.08
12	10	4	1		0.25	0.03		0.20	0.29	0.09
13	0	1	2		0.85	0.05		0.78	0.93	0.15
14	5	1	2		0.93	0.05		0.85	1.02	0.16
15	10	1	2		0.66	0.04		0.59	0.72	0.13
16	0	2	2		0.87	0.04		0.81	0.94	0.13
17	5	2	2		0.64	0.04		0.57	0.70	0.13
18	10	2	2		0.51	0.04		0.44	0.56	0.12
19	0	3	2		0.73	0.05		0.65	0.81	0.15
20	5	3	2		0.68	0.04		0.61	0.74	0.13
21	10	3	2		0.55	0.04		0.48	0.60	0.12
22	0	4	2		0.77	0.04		0.71	0.85	0.14
23	5	4	2		0.67	0.04		0.60	0.74	0.14
24	10	4	2		0.51	0.04		0.44	0.57	0.12
25	0	1	3		1.69	0.06		1.59	1.77	0.18
26	5	1	3		1.43	0.06		1.34	1.53	0.19
27	10	1	3		1.20	0.05		1.12	1.29	0.17
28	0	2	3		1.61	0.05		1.52	1.70	0.17
29	5	2	3		1.12	0.05		1.03	1.20	0.17
30	10	2	3		0.91	0.05		0.83	0.98	0.15
31	0	3	3		1.56	0.05		1.47	1.65	0.18
32	5	3	3		1.20	0.05		1.12	1.29	0.17
33	10	3	3		0.92	0.05		0.83	0.99	0.16
34	0	4	3		1.35	0.05		1.27	1.45	0.18
35	5	4	3		1.15	0.05		1.06	1.23	0.17
36	10	4	3		0.97	0.05		0.89	1.04	0.15
37	0	1	4		2.23	0.06		2.14	2.33	0.20
38	5	1	4		2.03	0.06		1.94	2.12	0.18
39	10	1	4		1.69	0.06		1.60	1.80	0.19
40	0	2	4		2.22	0.05		2.12	2.30	0.18
41	5	2	4		1.77	0.06		1.68	1.86	0.19
42	10	2	4		1.45	0.05		1.36	1.54	0.18
43	0	3	4		2.14	0.05		2.05	2.22	0.16
44	5	3	4		1.71	0.06		1.62	1.79	0.18
45	10	3	4		1.40	0.06		1.30	1.48	0.18
46	0	4	4		2.15	0.05		2.06	2.23	0.17
47	5	4	4		1.74	0.06		1.65	1.83	0.18
48	10	4	4		1.37	0.05		1.28	1.46	0.18

Table 4. Summary Statistics of the Total Number of Radars Killed (n = 300)

	Parameters							90 % Percentage Interval		
Combination #	Delay	MF	MGR		Mean	SE		Lower limit	Upper limit	PI length
1	0	1	1		3.17	0.04		3.10	3.24	0.14
2	5	1	1		2.87	0.04		2.80	2.94	0.14
3	10	1	1		2.63	0.05		2.54	2.70	0.16
4	0	2	1		3.15	0.04		3.07	3.21	0.13
5	5	2	1		2.78	0.05		2.70	2.86	0.16
6	10	2	1		2.45	0.05		2.37	2.54	0.17
7	0	3	1		3.07	0.04		2.99	3.14	0.15
8	5	3	1		2.64	0.05		2.56	2.72	0.16
9	10	3	1		2.39	0.05		2.30	2.46	0.17
10	0	4	1		2.99	0.04		2.91	3.06	0.14
11	5	4	1		2.56	0.05		2.47	2.63	0.16
12	10	4	1		2.26	0.05		2.17	2.35	0.18
13	0	1	2		3.67	0.03		3.62	3.72	0.10
14	5	1	2		3.68	0.03		3.63	3.72	0.09
15	10	1	2		3.36	0.04		3.28	3.42	0.14
16	0	2	2		3.67	0.03		3.61	3.71	0.09
17	5	2	2		3.46	0.04		3.40	3.52	0.12
18	10	2	2		3.26	0.04		3.19	3.33	0.14
19	0	3	2		3.59	0.03		3.53	3.63	0.10
20	5	3	2		3.40	0.04		3.34	3.46	0.13
21	10	3	2		3.16	0.05		3.08	3.23	0.15
22	0	4	2		3.54	0.03		3.48	3.59	0.11
23	5	4	2		3.35	0.04		3.28	3.41	0.13
24	10	4	2		3.27	0.04		3.20	3.34	0.14
25	0	1	3		3.84	0.02		3.79	3.87	0.07
26	5	1	3		3.78	0.02		3.74	3.82	0.08
27	10	1	3		3.71	0.03		3.66	3.75	0.09
28	0	2	3		3.81	0.02		3.77	3.84	0.08
29	5	2	3		3.67	0.03		3.63	3.72	0.09
30	10	2	3		3.57	0.03		3.50	3.61	0.11
31	0	3	3		3.81	0.02		3.77	3.84	0.08
32	5	3	3		3.72	0.03		3.66	3.75	0.09
33	10	3	3		3.64	0.03		3.59	3.68	0.10
34	0	4	3		3.74	0.03		3.69	3.78	0.09
35	5	4	3		3.56	0.03		3.50	3.61	0.11
36	10	4	3		3.56	0.03		3.51	3.62	0.11
37	0	1	4		3.93	0.01		3.90	3.95	0.05
38	5	1	4		3.87	0.02		3.84	3.90	0.06
39	10	1	4		3.79	0.03		3.74	3.83	0.08
40	0	2	4		3.93	0.02		3.90	3.95	0.05
41	5	2	4		3.88	0.02		3.85	3.91	0.06
42	10	2	4		3.75	0.03		3.70	3.79	0.09
43	0	3	4		3.88	0.02		3.84	3.91	0.07
44	5	3	4		3.76	0.03		3.71	3.79	0.09
45	10	3	4		3.77	0.02		3.72	3.81	0.08
46	0	4	4		3.90	0.02		3.86	3.92	0.06
47	5	4	4		3.83	0.02		3.79	3.86	0.07
48	10	4	4		3.79	0.02		3.75	3.83	0.07

Table 5. Summary Statistics of the Total Number of MSAMs Killed (n = 300)

	Parameters							90 % Percentage Interval		
Combination #	Delay	MF	MGR		Mean	SE		Lower limit	Upper limit	PI length
1	0	1	1		3.20	0.09		3.04	3.36	0.31
2	5	1	1		2.81	0.08		2.68	2.96	0.28
3	10	1	1		2.46	0.07		2.34	2.57	0.23
4	0	2	1		2.90	0.08		2.76	3.02	0.26
5	5	2	1		2.34	0.08		2.19	2.48	0.28
6	10	2	1		1.70	0.07		1.58	1.82	0.24
7	0	3	1		2.64	0.09		2.51	2.80	0.29
8	5	3	1		1.95	0.08		1.83	2.09	0.26
9	10	3	1		1.80	0.07		1.66	1.91	0.24
10	0	4	1		2.28	0.09		2.12	2.41	0.29
11	5	4	1		1.75	0.08		1.62	1.87	0.25
12	10	4	1		1.65	0.07		1.53	1.75	0.22
13	0	1	2		5.88	0.08		5.74	6.00	0.26
14	5	1	2		6.14	0.08		6.01	6.27	0.26
15	10	1	2		4.86	0.09		4.72	5.00	0.28
16	0	2	2		6.00	0.08		5.87	6.12	0.25
17	5	2	2		4.99	0.10		4.81	5.14	0.33
18	10	2	2		3.83	0.11		3.65	4.01	0.35
19	0	3	2		5.53	0.10		5.36	5.67	0.32
20	5	3	2		4.51	0.10		4.33	4.69	0.36
21	10	3	2		4.06	0.11		3.89	4.23	0.35
22	0	4	2		5.26	0.10		5.12	5.43	0.31
23	5	4	2		4.24	0.11		4.06	4.42	0.36
24	10	4	2		3.96	0.11		3.77	4.12	0.35
25	0	1	3		7.33	0.07		7.21	7.43	0.22
26	5	1	3		7.11	0.07		7.00	7.22	0.22
27	10	1	3		6.27	0.08		6.13	6.39	0.26
28	0	2	3		7.31	0.06		7.21	7.41	0.21
29	5	2	3		6.50	0.09		6.33	6.63	0.30
30	10	2	3		5.53	0.11		5.33	5.70	0.37
31	0	3	3		7.08	0.08		6.96	7.21	0.25
32	5	3	3		6.39	0.10		6.24	6.55	0.32
33	10	3	3		5.66	0.10		5.49	5.81	0.32
34	0	4	3		6.95	0.08		6.82	7.08	0.26
35	5	4	3		6.05	0.10		5.84	6.18	0.34
36	10	4	3		5.63	0.11		5.45	5.79	0.34
37	0	1	4		7.92	0.05		7.83	7.99	0.17
38	5	1	4		7.77	0.05		7.69	7.85	0.17
39	10	1	4		7.24	0.07		7.13	7.36	0.23
40	0	2	4		7.97	0.05		7.88	8.05	0.17
41	5	2	4		7.68	0.06		7.57	7.77	0.20
42	10	2	4		6.84	0.09		6.66	6.97	0.31
43	0	3	4		7.81	0.06		7.71	7.90	0.19
44	5	3	4		7.22	0.09		7.07	7.36	0.29
45	10	3	4		6.80	0.09		6.63	6.94	0.31
46	0	4	4		7.78	0.06		7.67	7.88	0.21
47	5	4	4		7.20	0.08		7.07	7.34	0.27
48	10	4	4		6.91	0.09		6.76	7.05	0.29

Table 6. Summary Statistics of the Total Number of SRSAMs Killed (n = 300)

	Parameters							90 % Percentage Interval		
Combination #	**Delay**	**MF**	**MGR**		**Mean**	**SE**		**Lower limit**	**Upper limit**	**PI length**
1	**0**	**1**	**1**		0.12	0.02		0.09	0.16	0.07
2	**5**	**1**	**1**		0.19	0.03		0.14	0.23	0.09
3	**10**	**1**	**1**		0.25	0.03		0.20	0.29	0.10
4	**0**	**2**	**1**		0.21	0.03		0.17	0.25	0.08
5	**5**	**2**	**1**		0.27	0.03		0.23	0.32	0.10
6	**10**	**2**	**1**		0.27	0.03		0.21	0.32	0.10
7	**0**	**3**	**1**		0.26	0.03		0.22	0.31	0.09
8	**5**	**3**	**1**		0.25	0.03		0.20	0.29	0.09
9	**10**	**3**	**1**		0.36	0.04		0.29	0.41	0.12
10	**0**	**4**	**1**		0.28	0.03		0.22	0.32	0.10
11	**5**	**4**	**1**		0.32	0.03		0.26	0.37	0.11
12	**10**	**4**	**1**		0.36	0.04		0.30	0.42	0.12
13	**0**	**1**	**2**		0.36	0.04		0.29	0.42	0.13
14	**5**	**1**	**2**		0.33	0.04		0.28	0.39	0.12
15	**10**	**1**	**2**		0.31	0.03		0.25	0.36	0.10
16	**0**	**2**	**2**		0.39	0.04		0.33	0.45	0.12
17	**5**	**2**	**2**		0.41	0.04		0.34	0.47	0.13
18	**10**	**2**	**2**		0.42	0.04		0.35	0.48	0.13
19	**0**	**3**	**2**		0.45	0.04		0.38	0.51	0.13
20	**5**	**3**	**2**		0.48	0.04		0.41	0.55	0.14
21	**10**	**3**	**2**		0.53	0.04		0.46	0.60	0.14
22	**0**	**4**	**2**		0.54	0.04		0.46	0.60	0.14
23	**5**	**4**	**2**		0.55	0.05		0.47	0.62	0.15
24	**10**	**4**	**2**		0.47	0.04		0.40	0.53	0.13
25	**0**	**1**	**3**		0.53	0.04		0.46	0.60	0.14
26	**5**	**1**	**3**		0.56	0.04		0.49	0.64	0.14
27	**10**	**1**	**3**		0.56	0.04		0.49	0.62	0.13
28	**0**	**2**	**3**		0.62	0.05		0.53	0.70	0.17
29	**5**	**2**	**3**		0.63	0.05		0.55	0.71	0.16
30	**10**	**2**	**3**		0.70	0.05		0.62	0.79	0.17
31	**0**	**3**	**3**		0.78	0.06		0.69	0.88	0.19
32	**5**	**3**	**3**		0.73	0.05		0.64	0.81	0.18
33	**10**	**3**	**3**		0.71	0.06		0.62	0.80	0.18
34	**0**	**4**	**3**		0.66	0.05		0.57	0.73	0.15
35	**5**	**4**	**3**		0.72	0.05		0.64	0.80	0.16
36	**10**	**4**	**3**		0.82	0.05		0.73	0.91	0.17
37	**0**	**1**	**4**		0.98	0.06		0.88	1.08	0.20
38	**5**	**1**	**4**		0.78	0.06		0.69	0.88	0.19
39	**10**	**1**	**4**		0.82	0.05		0.73	0.91	0.17
40	**0**	**2**	**4**		0.92	0.07		0.82	1.03	0.21
41	**5**	**2**	**4**		0.89	0.06		0.79	0.97	0.18
42	**10**	**2**	**4**		0.86	0.06		0.77	0.95	0.18
43	**0**	**3**	**4**		0.87	0.06		0.79	0.99	0.20
44	**5**	**3**	**4**		0.99	0.06		0.88	1.08	0.20
45	**10**	**3**	**4**		0.91	0.06		0.82	1.01	0.19
46	**0**	**4**	**4**		1.06	0.06		0.95	1.16	0.21
47	**5**	**4**	**4**		0.88	0.06		0.79	0.98	0.19
48	**10**	**4**	**4**		1.01	0.06		0.93	1.11	0.18

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